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APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/955,485	03/03/2020	10581469	44837-0005001	1028

26171 7590 02/12/2020
FISH & RICHARDSON P.C. (DC)
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022

ISSUE NOTIFICATION

The projected patent number and issue date are specified above.

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b) (application filed on or after May 29, 2000)

The Patent Term Adjustment is 0 day(s). Any patent to issue from the above-identified application will include an indication of the adjustment on the front page.

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) WEB site (<http://pair.uspto.gov>).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Application Assistance Unit (AAU) of the Office of Data Management (ODM) at (571)-272-4200.

APPLICANT(s) (Please see PAIR WEB site <http://pair.uspto.gov> for additional applicants):

DeepSig Inc., Arlington, VA
Timothy James O'Shea, Arlington, VA;
James Shea, Arlington, VA;

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The USA offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to encourage and facilitate business investment. To learn more about why the USA is the best country in the world to develop technology, manufacture products, and grow your business, visit SelectUSA.gov.



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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
15/955,485	04/17/2018	Timothy James O'Shea	44837-0005001

26171
FISH & RICHARDSON P.C. (DC)
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022

CONFIRMATION NO. 1028
POA ACCEPTANCE LETTER



Date Mailed: 01/24/2020

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 01/22/2020.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at (571) 272-4000 or (571) 272-4200 or 1-888-786-0101.

/nhorne/

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor : Timothy James O'Shea Art Unit : 2649
Application No. : 15/955,485 Examiner : Sonny Trinh
Filed : April 17, 2018 Confirmation No. : 1028
Notice of Allowance Date: October 23, 2019
Title: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

MAIL STOP ISSUE FEE

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

REPLY TO NOTICE OF ALLOWANCE

In response to the Notice of Allowance dated October 23, 2019, enclosed is a completed Part B - Fee(s) Transmittal.

The issue fee is being paid with this reply on the Electronic Filing System. Apply those fees and any other necessary charges or credits to Deposit Account 06-1050, referencing the above attorney docket number.

COMMENTS ON EXAMINER'S REASONS FOR ALLOWANCE

It is recognized that in accordance with M.P.E.P. § 1302.14, the Examiner's reasons for allowance need not set forth all of the details as to why the claims are allowed. In the above-referenced application, it is not conceded that the Examiner's stated reasons for allowance are the only reasons for which the claims are allowable. The Examiner's reasons for allowance indicate that particular claim elements are not disclosed or suggested by the prior art of record, yet the claims may be patentable for other reasons as well, including the inventive combination of all of the recited claim elements. It is not conceded that the specific limitations identified by the Examiner are necessary to distinguish the art of record or to satisfy the requirements of 35 U.S.C. § 112. Moreover, the Examiner does not assert, and it would not be conceded, that the Examiner's reasons have any bearing on the patentability of claims in any other applications directed to the disclosed subject matter.

First Named Inventor : Timothy James O'Shea
Application No. : 15/955,485
Filed : April 17, 2018
Page : 2 of 2

Attorney Docket: 44837-0005001

In addition, each dependent claim stands on its own and may be allowable on its own merits. In particular, each dependent claim may be allowable on the basis of a combination of some of the features recited in the dependent claim and its base claim(s), which combination of features may not include all of the limitations identified in the Examiner's reasons for allowance.

Respectfully submitted,

Date: January 22, 2020

/Ayan Roy-Chowdhury/
Ayan Roy-Chowdhury
Reg. No. 72,483

Customer Number 26171
Fish & Richardson P.C.
Telephone: +1 (202) 626-6428
Facsimile: (877) 769-7945

41422162.doc

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), by mail or fax, or via EFS-Web

By mail, send to: Mail Stop ISSUE FEE
 Commissioner for Patents
 P.O. Box 1450
 Alexandria, Virginia 22314-1450

By fax, send to: (571) 273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

26171 7590 10/23/2019

FISH & RICHARDSON P.C.
 P.O. BOX 1022
 MINNEAPOLIS, MN 55440-1022

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being transmitted to the USPTO via EFS-Web or by facsimile to (571) 273-2885, on the date below.

(Typed or printed name)

(Signature)

(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/955,485	04/17/2018	Timothy James O'Shea	44837-0005001	1028

TITLE OF INVENTION: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	\$500	\$0	\$0	\$500	01/23/2020

EXAMINER	ART UNIT	CLASS-SUBCLASS
TRINH, SONNY	2649	455-114300

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

- ☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.
- ☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-09 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list

- (1) The names of up to 3 registered patent attorneys or agents OR, alternatively, 1 Fish & Richardson P.C.
- (2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed. 2 _____
- 3 _____

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE
 DeepSig Inc.

(B) RESIDENCE: (CITY and STATE OR COUNTRY)
 Arlington, VA

Please check the appropriate assignee category or categories (will not be printed on the patent): ☐ Individual ☒ Corporation or other private group entity ☐ Government4a. Fees Submitted: ☒ Issue Fee ☐ Publication Fee (if required) ☐ Advance Order - # of Copies

4b. Method of Payment (Please first reapply any previously paid fee shown above):

- ☐ Electronic Payment via EFS-Web ☐ Enclosed check ☐ Non-electronic payment by credit card (Attach form PTO-2038)
- ☒ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment, to Deposit Account No. 06-1050

5. Change of Entity Status (from status indicated above)

- ☐ Applicant certifying micro entity status. See 37 CFR 1.29
- ☐ Applicant asserting small entity status. See 37 CFR 1.27.
- ☐ Applicant changing to regular undiscounted fee status.

NOTE: Absent a valid Certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.

NOTE: If the application was previously under micro entity status, checking this box will be taken as a notification of loss of entitlement to micro entity status.

NOTE: Checking this box will be taken as a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature /Ayan Roy-Chowdhury/Date 01/22/2020Typed or printed name Ayan Roy-ChowdhuryRegistration No. 72,483

Electronic Patent Application Fee Transmittal

Application Number:	15955485			
Filing Date:	17-Apr-2018			
Title of Invention:	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM			
First Named Inventor/Applicant Name:	Timothy James O'Shea			
Filer:	Ayan Roy-Chowdhury/Sharon Allen			
Attorney Docket Number:	44837-0005001			
Filed as Small Entity				
Filing Fees for Utility under 35 USC 111(a)				
Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
UTILITY APPL ISSUE FEE	2501	1	500	500

Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Extension-of-Time:				
Miscellaneous:				
Total in USD (\$)				500

Electronic Acknowledgement Receipt

EFS ID:	38363866
Application Number:	15955485
International Application Number:	
Confirmation Number:	1028
Title of Invention:	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM
First Named Inventor/Applicant Name:	Timothy James O'Shea
Customer Number:	26171
Filer:	Ayan Roy-Chowdhury/Sharon Allen
Filer Authorized By:	Ayan Roy-Chowdhury
Attorney Docket Number:	44837-0005001
Receipt Date:	22-JAN-2020
Filing Date:	17-APR-2018
Time Stamp:	12:38:20
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	DA
Payment was successfully received in RAM	\$ 500
RAM confirmation Number	E20201LC38522890
Deposit Account	061050
Authorized User	Sharon Allen

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:
37 CFR 1.21 (Miscellaneous fees and charges)

File Listing:					
Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		44837-0005001-IssueFee.pdf	242755	yes	3
			90213703a84de04e09d683e88a8974dd08aeb74b		
	Multipart Description/PDF files in .zip description				
	Document Description		Start	End	
	Transmittal Letter		1	2	
	Issue Fee Payment (PTO-85B)		3	3	
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	30351	no	2
			a70bcc6f427bd5f892480780cdb32c8bc34b9c67		
Warnings:					
Information:					
Total Files Size (in bytes):			273106		
This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503. <u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application. <u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course. <u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.					

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor : Timothy James O'Shea Art Unit : 2649
Application No. : 15/955,485 Examiner : Sonny Trinh
Filed : April 17, 2018 Conf. No. : 1028

Title: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

MAIL STOP MISSING PARTS

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

RESPONSE TO INFORMATIONAL NOTICE TO APPLICANT

In response to the Informational Notice to Applicant mailed May 16, 2018,
applicant claims small entity status (see 37 CFR §1.27) and submits herewith the following:

- ☒ Declaration in compliance with 37 CFR §1.63;
- ☒ Transmittal and Power of Attorney in compliance with 37 CFR § 1.32;
- ☒ Statement Under 37 CFR 3.73(c) on behalf of Assignee; and
- ☒ Copy of Recordation of Assignment.

Please apply any necessary charges or credits to Deposit Account 06-1050, referencing
the above attorney docket number.

It is understood that this perfects the application and no additional papers or filing fees
are required.

Respectfully submitted,

Date: January 22, 2020

/Ayan Roy-Chowdhury/

Ayan Roy-Chowdhury
Reg. No. 72,483

Customer Number 26171
Fish & Richardson P.C.
Telephone: +1 (202) 626-6428
Facsimile: (877) 769-7945

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

**DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN
APPLICATION DATA SHEET (37 CFR 1.76)****Title of
Invention**

LEARNING BASED RADIO AMPLIFIER NON-LINEARITY PRE-DISTORTION SYSTEM

As the below named inventor, I hereby declare that:

This declaration ☐ The attached application, or
is directed to:☒ United States application or PCT international application number 15/955,485filed on April 17, 2018

The above-identified application was made or authorized to be made by me.

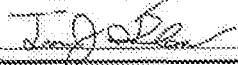
I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001
by fine or imprisonment of not more than five (5) years, or both.**WARNING:**

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

LEGAL NAME OF INVENTORInventor: Timothy James O'Shea

Date (Optional): _____

Signature: 

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 116 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1 minute to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of
Invention

LEARNING BASED RADIO AMPLIFIER NON-LINEARITY PRE-DISTORTION SYSTEM

As the below named inventor, I hereby declare that:

This declaration ☐ The attached application, or
is directed to:

☒ United States application or PCT international application number 15/955,485
 filed on April 17, 2018

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

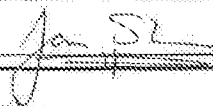
I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

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Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

LEGAL NAME OF INVENTOR

Inventor: James Shea Date (Optional)

Signature: 

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1 minute to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

TRANSMITTAL FOR POWER OF ATTORNEY TO ONE OR MORE REGISTERED PRACTITIONERS

Application Number	15/955,485
Filing Date	April 17, 2018
First Named Inventor	Timothy M. O'Shea
Title	LEARNING BASED RADIO AMPLIFIER NON-LINEARITY PRE-DISTORTION SYSTEM
Art Unit	2649
Examiner Name	Sonny Trinh
Attorney Docket Number	44837-0005001

SIGNATURE of Applicant or Patent Practitioner

Signature	/Ayan Roy-Chowdhury/	Date (Optional)	January 22, 2020
Name	Ayan Roy-Chowdhury	Registration Number	72,483
Title (if Applicant is a juristic entity)			
Applicant Name (if Applicant is a juristic entity)			
NOTE: This form must be signed in accordance with 37 CFR 1.33. See 37 CFR 1.4(d) for signature requirements and certifications. If more than one applicant, use multiple forms.			
☐ *Total of _____ forms are submitted.			

POWER OF ATTORNEY BY APPLICANT

I hereby revoke all previous powers of attorney given in the application identified in either the attached transmittal letter or the boxes below.

Application Number	Filing Date

(Note: The boxes above may be left blank if information is provided on the Transmittal.)

- ☒ I hereby appoint the Patent Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the application referenced in the attached transmittal letter, which may be an application filed after the date of this power of attorney, or identified above:

26171

OR

- ☐ I hereby appoint Practitioner(s) named in the attached list as my/our attorney(s) or agent(s), and to transact all business in the United States Patent and Trademark Office connected therewith for the patent application referenced in the attached transmittal letter, which may be an application filed after the date of this power of attorney, or identified above.

Please recognize or change the correspondence address for the application identified in the attached transmittal letter to:

- ☒ The address associated with the above-mentioned Customer Number

OR

- ☐ The address associated with Customer Number: 26171

OR

Firm or Individual Name			
Address			
City	State	Zip	
Country			
Telephone	Email		

I am the Applicant (if the Applicant is a juristic entity, list the Applicant name in the box):

DeepSig Inc.

- ☐ Inventor or Joint Inventor (title not required below)
- ☐ Legal Representative of a Deceased or Legally Incapacitated Inventor (title not required below)
- ☒ Assignee or Person to Whom the Inventor is Under an Obligation to Assign (provide signer's title if applicant is a juristic entity)
- ☐ Person Who Otherwise Shows Sufficient Proprietary Interest (e.g., a petition under 37 CFR 1.46(b)(2) was granted in the application or is concurrently being filed with this document) (provide signer's title if applicant is a juristic entity)

SIGNATURE of Applicant for Patent

The undersigned (whose title is supplied below) is authorized to act on behalf of the applicant (e.g., where the applicant is a juristic entity).

Signature		Date (Optional)	10/2/2016
Name	Timothy James O'Shea		
Title	CTO, DeepSig Inc		

NOTE: Signature - This form must be signed by the applicant in accordance with 37 CFR 1.33. See 37 CFR 1.4 for signature requirements and certifications. If more than one applicant, use multiple forms.

- ☐ *Total of _____ forms are submitted.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

STATEMENT UNDER 37 CFR 3.73(e)Applicant/Patent Owner: DeepSig Inc.Application No./Patent No.: 15/955,485 Filed/Issue Date: April 17, 2018Titled: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEMDeepSig Inc. a Corporation

(Name of Assignee)

(Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that, for the patent application/patent identified above, it is (choose one of the option 1, 2, 3 or 4 below):

1. ☒ The assignee of the entire right, title, and interest.
2. ☐ An assignee of less than the entire right, title and interest (check applicable box):
- ☐ The extent (by percentage) of its ownership interest is _____. Additional Statement(s) by the owners holding the balance of the interest must be submitted to account for 100% of the ownership interest.
- ☐ There are unspecified percentages of ownership. The other parties, including inventors, who together own the entire right, title and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

3. ☐ The assignee of an undivided interest in the entirety (a complete assignment from one of the joint inventors was made). The other parties, including inventors, who together own the entire right, title, and interest are:

Additional Statement(s) by the owner(s) holding the balance of the interest must be submitted to account for the entire right, title, and interest.

4. ☐ The recipient, via a court proceeding or the like (e.g., bankruptcy, probate), of an undivided interest in the entirety (a complete transfer of ownership interest was made). The certified document(s) showing the transfer is attached.

The interest identified in option 1, 2 or 3 above (not option 4) is evidenced by either (choose one of the options A or B below):

- A. ☒ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel 051531, Frame 0194, or for which a copy thereof is attached.
- B. ☐ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: _____ To: _____
The document was recorded in the United States Patent and Trademark Office at Reel _____, Frame _____, or for which a copy thereof is attached.
2. From: _____ To: _____
The document was recorded in the United States Patent and Trademark Office at Reel _____, Frame _____, or for which a copy thereof is attached.

[Page 1 of 2]

This collection of information is required by 37 CFR 3.73(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

STATEMENT UNDER 37 CFR 3.73(c)

3. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at
Reel _____, Frame _____, or for which a copy thereof is attached.

4. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at
Reel _____, Frame _____, or for which a copy thereof is attached.

5. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at
Reel _____, Frame _____, or for which a copy thereof is attached.

6. From: _____ To: _____

The document was recorded in the United States Patent and Trademark Office at
Reel _____, Frame _____, or for which a copy thereof is attached.☐ Additional documents in the chain of title are listed on a supplemental sheet(s).☒ As required by 37 CFR 3.73(c)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

/Ayan Roy-Chowdhury/

Signature

January 22, 2020

Date

Ayan Roy-Chowdhury

Printed or Typed Name

72,483

Title or Registration Number



COPY

UNITED STATES PATENT AND TRADEMARK OFFICE

UNDER SECRETARY OF COMMERCE FOR INTELLECTUAL PROPERTY AND
DIRECTOR OF THE UNITED STATES PATENT AND TRADEMARK OFFICE

JANUARY 17, 2020

PTAS

AYAN ROY-CHOWDHURY
FISH & RICHARDSON P.C.
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022

505867312

UNITED STATES PATENT AND TRADEMARK OFFICE
NOTICE OF RECORDATION OF ASSIGNMENT DOCUMENT

THE ENCLOSED DOCUMENT HAS BEEN RECORDED BY THE ASSIGNMENT RECORDATION BRANCH OF THE U.S. PATENT AND TRADEMARK OFFICE. A COMPLETE COPY IS AVAILABLE AT THE ASSIGNMENT SEARCH ROOM ON THE REEL AND FRAME NUMBER REFERENCED BELOW.

PLEASE REVIEW ALL INFORMATION CONTAINED ON THIS NOTICE. THE INFORMATION CONTAINED ON THIS RECORDATION NOTICE REFLECTS THE DATA PRESENT IN THE PATENT AND TRADEMARK ASSIGNMENT SYSTEM. IF YOU SHOULD FIND ANY ERRORS OR HAVE QUESTIONS CONCERNING THIS NOTICE, YOU MAY CONTACT THE ASSIGNMENT RECORDATION BRANCH AT 571-272-3350. PLEASE SEND REQUEST FOR CORRECTION TO: U.S. PATENT AND TRADEMARK OFFICE, MAIL STOP: ASSIGNMENT RECORDATION BRANCH, P.O. BOX 1450, ALEXANDRIA, VA 22313.

RECORDATION DATE: 01/16/2020

REEL/FRAME: 051531/0194
NUMBER OF PAGES: 3

BRIEF: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).

DOCKET NUMBER: 44837-0005001

ASSIGNOR:
O'SHEA, TIMOTHY JAMES

DOC DATE: 01/16/2020

ASSIGNOR:
SHEA, JAMES

DOC DATE: 01/16/2020

ASSIGNEE:
DEEPSIG INC.
1201 WILSON BLVD, FL 27
ARLINGTON, VIRGINIA 22209

APPLICATION NUMBER: 15955485
PATENT NUMBER:
TITLE: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

FILING DATE: 04/17/2018
ISSUE DATE:

ASSIGNMENT RECORDATION BRANCH
PUBLIC RECORDS DIVISION

PATENT ASSIGNMENT COVER SHEET

Electronic Version v1.1
 Stylesheet Version v1.2

EPAS ID: PAT5914140

SUBMISSION TYPE:	NEW ASSIGNMENT
NATURE OF CONVEYANCE:	ASSIGNMENT
CONVEYING PARTY DATA	
Name	Execution Date
Timothy James O'Shea	01/16/2020
James Shea	01/16/2020
RECEIVING PARTY DATA	
Name:	DEEPSIG INC.
Street Address:	1201 WILSON BLVD, FL 27
City:	ARLINGTON
State/Country:	VIRGINIA
Postal Code:	22209
PROPERTY NUMBERS Total: 1	
Property Type	Number
Application Number:	15955485
CORRESPONDENCE DATA	
Fax Number:	(877)769-7945
<i>Correspondence will be sent to the e-mail address first; if that is unsuccessful, it will be sent using a fax number, if provided; if that is unsuccessful, it will be sent via US Mail.</i>	
Phone:	+1 (202) 626-6428
Email:	apsi@fr.com
Correspondent Name:	AYAN ROY-CHOWDHURY
Address Line 1:	FISH & RICHARDSON P.C.
Address Line 2:	P.O.BOX 1022
Address Line 4:	MINNEAPOLIS, MINNESOTA 55440-1022
ATTORNEY DOCKET NUMBER:	44837-0005001
NAME OF SUBMITTER:	SHARON M. ALLEN
SIGNATURE:	/Sharon M. Allen/
DATE SIGNED:	01/16/2020
Total Attachments: 2	
source=44837-0005001 Assignment #page1.tif	
source=44837-0005001 Assignment #page2.tif	

ASSIGNMENT

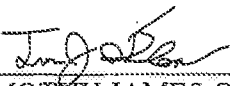
For valuable consideration, the receipt of which we acknowledge, and intending to be bound legally, we, TIMOTHY JAMES O'SHEA, and JAMES SHEA, each individually assign to DEEPSIG INC., a corporation formed under the laws of Delaware and having a principal place of business at 1201 Wilson Blvd, FL27, Arlington VA 22209, and its successors, transferees, and assignees (collectively the "Assignee"), all of our individual and joint right, title, and interest throughout the world in the subject matter (the "Subject Matter") of a patent application that names us as inventors, is titled "LEARNING BASED RADIO AMPLIFIER NON-LINEARITY PRE-DISTORTION SYSTEM," and was filed in the United States Patent and Trademark Office on April 17, 2018, as application 15/955,485 (the "Application").

This Assignment assigns (a) the Application and all other applications that may be made for, and all patents, utility models, design registrations, and other rights of exclusion and inventors' certificates for, any of the Subject Matter (collectively the "Applications and Granted Rights") in every country or region, (b) the right to claim priority based on and the benefit of the filing date of any of the Applications and Granted Rights under the International Convention for the Protection of Industrial Property, the Patent Cooperation Treaty, the European Patent Convention, and all other applicable treaties or conventions, and (c) the right to pursue, collect, and retain in the Assignee's name or otherwise, damages and any other remedies arising from any past, present, or future infringement of the Subject Matter, the Applications and Granted Rights, and any other rights assigned by this Assignment.

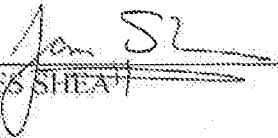
We authorize the Assignee to apply for and pursue protection for any or all of the Subject Matter, the Applications and Granted Rights, and any other rights assigned by this Assignment in all countries, regions, and territories of the world, in our names or in the Assignee's name.

We represent and warrant that we have the right and power to make this Assignment and that we have not made and will not make any other assignment that conflicts with this Assignment.

We will communicate to the Assignee (or at the request of the Assignee to other parties) all known facts in any form relating to the Subject Matter, will execute and provide all oaths and declarations, statements, testimony, assignments, powers of attorney, applications, and documents, and will perform all other lawful acts necessary or desirable to secure fully to the Assignee the rights, titles, and interests assigned by this Assignment.


TIMOTHY JAMES O'SHEA

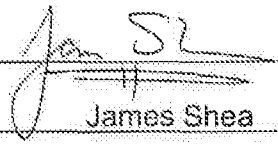
Date: Jan 16, 2020


JAMES SHEA

Date: January 16, 2020

The Assignee hereby acknowledges and accepts the foregoing assignment.

Assignee: DEEPSIG INC.

Signature:  Date: January 16, 2020
Name: James Shea
Title: CEO

41327562.doc

Electronic Acknowledgement Receipt

EFS ID:	38363611
Application Number:	15955485
International Application Number:	
Confirmation Number:	1028
Title of Invention:	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM
First Named Inventor/Applicant Name:	Timothy James O'Shea
Customer Number:	26171
Filer:	Ayan Roy-Chowdhury/Sharon Allen
Filer Authorized By:	Ayan Roy-Chowdhury
Attorney Docket Number:	44837-0005001
Receipt Date:	22-JAN-2020
Filing Date:	17-APR-2018
Time Stamp:	12:26:41
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no
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File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		44837-0005001-Missing.pdf	715163	yes	11
			146bbd5e43b0475d68fe9440d48e2dadcf a9c45		

	Multipart Description/PDF files in .zip description		
	Document Description	Start	End
	Applicant Response to Pre-Exam Formalities Notice	1	1
	Oath or Declaration filed	2	3
	Power of Attorney	4	5
	Assignee showing of ownership per 37 CFR 3.73	6	7
	Miscellaneous Incoming Letter	8	11

Warnings:

Information:

Total Files Size (in bytes):	715163
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This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

NOTICE OF ALLOWANCE AND FEE(S) DUE

26171 7590 10/23/2019
FISH & RICHARDSON P.C. (DC)
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022

EXAMINER

TRINH, SONNY

ART UNIT

PAPER NUMBER

2649

DATE MAILED: 10/23/2019

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/955,485	04/17/2018	Timothy James O'Shea	44837-0005001	1028

TITLE OF INVENTION: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	\$500	\$0.00	\$0.00	\$500	01/23/2020

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE DOES NOT REFLECT A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE IN THIS APPLICATION. IF AN ISSUE FEE HAS PREVIOUSLY BEEN PAID IN THIS APPLICATION (AS SHOWN ABOVE), THE RETURN OF PART B OF THIS FORM WILL BE CONSIDERED A REQUEST TO REAPPLY THE PREVIOUSLY PAID ISSUE FEE TOWARD THE ISSUE FEE NOW DUE.

HOW TO REPLY TO THIS NOTICE:

I. Review the ENTITY STATUS shown above. If the ENTITY STATUS is shown as SMALL or MICRO, verify whether entitlement to that entity status still applies.

If the ENTITY STATUS is the same as shown above, pay the TOTAL FEE(S) DUE shown above.

If the ENTITY STATUS is changed from that shown above, on PART B - FEE(S) TRANSMITTAL, complete section number 5 titled "Change in Entity Status (from status indicated above)".

For purposes of this notice, small entity fees are 1/2 the amount of undiscounted fees, and micro entity fees are 1/2 the amount of small entity fees.

II. PART B - FEE(S) TRANSMITTAL, or its equivalent, must be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted. If an equivalent of Part B is filed, a request to reapply a previously paid issue fee must be clearly made, and delays in processing may occur due to the difficulty in recognizing the paper as an equivalent of Part B.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Maintenance fees are due in utility patents issuing on applications filed on or after Dec. 12, 1980. It is patentee's responsibility to ensure timely payment of maintenance fees when due. More information is available at www.uspto.gov/PatentMaintenanceFees.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), by mail or fax, or via EFS-Web.

By mail, send to: Mail Stop ISSUE FEE
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

By fax, send to: (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

26171 7590 10/23/2019
FISH & RICHARDSON P.C. (DC)
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being transmitted to the USPTO via EFS-Web or by facsimile to (571) 273-2885, on the date below.

(Typed or printed name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/955,485	04/17/2018	Timothy James O'Shea	44837-0005001	1028

TITLE OF INVENTION: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	\$500	\$0.00	\$0.00	\$500	01/23/2020

EXAMINER	ART UNIT	CLASS-SUBCLASS
TRINH, SONNY	2649	455-114300

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-09 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list

(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,

1 _____

(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

2 _____

3 _____

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE

(B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) : ☐ Individual ☐ Corporation or other private group entity ☐ Government

4a. Fees submitted: ☐ Issue Fee ☐ Publication Fee (if required) ☐ Advance Order - # of Copies _____

4b. Method of Payment: (Please first reapply any previously paid fee shown above)

☐ Electronic Payment via EFS-Web ☐ Enclosed check ☐ Non-electronic payment by credit card (Attach form PTO-2038)

☐ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment to Deposit Account No. _____

5. **Change in Entity Status** (from status indicated above)

☐ Applicant certifying micro entity status. See 37 CFR 1.29

☐ Applicant asserting small entity status. See 37 CFR 1.27

☐ Applicant changing to regular undiscounted fee status.

NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.

NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.

NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature _____

Date _____

Typed or printed name _____

Registration No. _____



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/955,485	04/17/2018	Timothy James O'Shea	44837-0005001	1028
26171	7590	10/23/2019	EXAMINER	
FISH & RICHARDSON P.C. (DC)			TRINH, SONNY	
P.O. BOX 1022			ART UNIT	
MINNEAPOLIS, MN 55440-1022			PAPER NUMBER	
			2649	
DATE MAILED: 10/23/2019				

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b) (Applications filed on or after May 29, 2000)

The Office has discontinued providing a Patent Term Adjustment (PTA) calculation with the Notice of Allowance.

Section 1(h)(2) of the AIA Technical Corrections Act amended 35 U.S.C. 154(b)(3)(B)(i) to eliminate the requirement that the Office provide a patent term adjustment determination with the notice of allowance. See Revisions to Patent Term Adjustment, 78 Fed. Reg. 19416, 19417 (Apr. 1, 2013). Therefore, the Office is no longer providing an initial patent term adjustment determination with the notice of allowance. The Office will continue to provide a patent term adjustment determination with the Issue Notification Letter that is mailed to applicant approximately three weeks prior to the issue date of the patent, and will include the patent term adjustment on the patent. Any request for reconsideration of the patent term adjustment determination (or reinstatement of patent term adjustment) should follow the process outlined in 37 CFR 1.705.

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at 1-(888)-786-0101 or (571)-272-4200.

<i>Notice Requiring Inventor's Oath or Declaration</i>	Application No. 15/955,485	Applicant(s) Timothy James O'Shea	
	Examiner TRINH, SONNY	Art Unit 2649	

This notice is an attachment to the Notice of Allowability (PTOL-37), or the Notice of Allowability For A Design Application (PTOL-37D).

An inventor's oath or declaration in compliance with 37 CFR 1.63 or 1.64 executed by or with respect to each inventor has not yet been submitted.

An oath or declaration in compliance with 37 CFR 1.63, or a substitute statement in compliance with 37 CFR 1.64, executed by or with respect to each inventor (for any inventor for which a compliant oath, declaration, or substitute statement has not yet been submitted) **MUST** be filed no later than the date on which the issue fee is paid. See 35 U.S.C. 115(f). Failure to timely comply will result in ABANDONMENT of this application.

A properly executed inventor's oath to declaration has not been received for the following inventor(s):

If applicant previously filed one or more oaths, declarations, or substitute statements, applicant may have received an informational notice regarding deficiencies therein.

The following deficiencies are noted:

INFORMAL ACTION PROBLEMS

- A properly executed inventor's oath or declaration has not been received for the following inventor(s): **Timothy James O'Shea** and **James Shea**.

Applicant may submit the inventor's oath or declaration at any time before the Notice of Allowance and Fee(s) Due, PTOL-85, is mailed.

Questions relating to this Notice should be directed to the Application Assistance Unit at 571-272-4200.

OMB Clearance and PRA Burden Statement for PTOL-85 Part B

The Paperwork Reduction Act (PRA) of 1995 requires Federal agencies to obtain Office of Management and Budget approval before requesting most types of information from the public. When OMB approves an agency request to collect information from the public, OMB (i) provides a valid OMB Control Number and expiration date for the agency to display on the instrument that will be used to collect the information and (ii) requires the agency to inform the public about the OMB Control Number's legal significance in accordance with 5 CFR 1320.5(b).

The information collected by PTOL-85 Part B is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 30 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450. Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Notice of Allowability	Application No. 15/955,485	Applicant(s) O'Shea et al.	
	Examiner SONNY TRINH	Art Unit 2649	AIA (FITF) Status Yes

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☒ This communication is responsive to amendment, Arguments/Remarks filed 07/15/19.
☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on ____.

2. ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on ____; the restriction requirement and election have been incorporated into this action.

3. ☒ The allowed claim(s) is/are 1-2 and 5-26. As a result of the allowed claim(s), you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to PPHfeedback@uspto.gov.

4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

Certified copies:

a) ☐ All b) ☐ Some *c) ☐ None of the:

1. ☐ Certified copies of the priority documents have been received.

2. ☐ Certified copies of the priority documents have been received in Application No. ____.

3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

* Certified copies not received: ____.

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date ____.

Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).

6. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☐ Notice of References Cited (PTO-892)	5. ☐ Examiner's Amendment/Comment
2. ☐ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date ____.	6. ☐ Examiner's Statement of Reasons for Allowance
3. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material ____.	7. ☐ Other ____.
4. ☐ Interview Summary (PTO-413), Paper No./Mail Date. ____.	

/SONNY TRINH/ Primary Examiner, Art Unit 2649	
--	--

<i>Index of Claims</i> 	Application/Control No. 15/955,485	Applicant(s)/Patent Under Reexamination O'Shea et al.
	Examiner SONNY TRINH	Art Unit 2649

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

CLAIMS										
☐ Claims renumbered in the same order as presented by applicant					☐ CPA		☐ T.D.		☐ R.1.47	
CLAIM		DATE								
Final	Original	04/09/2019	10/04/2019							
1	1	✓	=							
2	2	○	-							
-	3	✓	-							
-	4	○	=							
6	5	✓	=							
3	6	○	=							
4	7	○	=							
5	8	○	=							
7	9	✓	=							
8	10	=	=							
9	11	=	=							
10	12	=	=							
12	13	=	=							
11	14	=	=							
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20	22	=	=							
21	23	✓	=							
23	24	✓	=							
24	25		=							
22	26		=							

<i>Search Notes</i> 	Application/Control No. 15/955,485	Applicant(s)/Patent Under Reexamination O'Shea et al.
	Examiner SONNY TRINH	Art Unit 2649

CPC - Searched*		
Symbol	Date	Examiner
h04b1/0475 g06n3/08 h04w88/08	04/09/2019	ST

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner
455	501,63.1,67.13,114.3	04/09/2019	ST

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	Date	Examiner
EAST, CPC, Inventors	04/09/2019	ST
Updated	10/04/2019	ST

Interference Search			
US Class/CPC Symbol	US Subclass/CPC Group	Date	Examiner
H04B	1/04	10/04/2019	ST

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<i>Issue Classification</i> 	Application/Control No. 15/955,485	Applicant(s)/Patent Under Reexamination O'Shea et al.
	Examiner SONNY TRINH	Art Unit 2649

CPC						
Symbol				Type	Version	
H04B	/	1	/	0475	F	2013-01-01
G06N	/	3	/	04	I	2013-01-01
G06N	/	3	/	08	I	2013-01-01
H04W	/	88	/	08	A	2013-01-01

CPC Combination Sets							
Symbol				Type	Set	Ranking	Version
	/		/				

NONE (Assistant Examiner) _____ (Date) _____		Total Claims Allowed: 22	
/SONNY TRINH/ Primary Examiner, Art Unit 2649 (Primary Examiner) _____ (Date) 04 October 2019		O.G. Print Claim(s) 1	O.G. Print Figure 1

Issue Classification 	Application/Control No. 15/955,485	Applicant(s)/Patent Under Reexamination O'Shea et al.
	Examiner SONNY TRINH	Art Unit 2649

INTERNATIONAL CLASSIFICATION			
CLAIMED			
H04B	/	1	/ 04
NON-CLAIMED			
/		/	

US ORIGINAL CLASSIFICATION	
CLASS	SUBCLASS
455	114.3

CROSS REFERENCES(S)						
CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)					

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	22	
/SONNY TRINH/ Primary Examiner, Art Unit 2649 (Primary Examiner)	04 October 2019 (Date)	O.G. Print Claim(s) 1	O.G. Print Figure 1

Issue Classification 	Application/Control No. 15/955,485	Applicant(s)/Patent Under Reexamination O'Shea et al.
	Examiner SONNY TRINH	Art Unit 2649

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47															
CLAIMS															
Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1	8	10	17	19										
2	2	9	11	18	20										
-	3	10	12	19	21										
-	4	12	13	20	22										
6	5	11	14	21	23										
3	6	13	15	23	24										
4	7	14	16	24	25										
5	8	15	17	22	26										
7	9	16	18												

NONE (Assistant Examiner) _____ (Date) _____		Total Claims Allowed: 22	
/SONNY TRINH/ Primary Examiner, Art Unit 2649 (Primary Examiner) _____ (Date) 04 October 2019		O.G. Print Claim(s) 1	O.G. Print Figure 1

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	91980	(h04b1/0475 g06n3/08 h04w88/08).cpc.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 05:37
L2	13135	455/501,63.1,67.13,114.3.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 05:37
L3	104270	L1 or L2	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 05:37
L4	3083	nonlinear with (pre-distort\$3 predistort\$3)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 05:38
L5	25	4 and learn\$4 near2 model	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 05:38
L6	5	(distance near3 metric) same predistort\$3	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 05:39
L7	1017	3 and correct\$3 near4 distortion	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 06:30
L8	0	7 and (deployment near3 initial) with	US-PGPUB;	OR	ON	2019/10/04

		communication	USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			06:30
L9	13135	455/501,63.1,67.13,114.3.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 06:31
L10	13135	3 and 9	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 06:31
L11	235	4 and 10	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 06:31
L12	1	11 and learn\$4 near2 model	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 06:32
L13	0	15/955485	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/10/04 06:38
S1	0	15/955485	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:16
S2	162	((("O'SHEA") near3 ("Timothy"))) OR (("SHEA") near3 ("James"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	OFF	2019/04/09 07:16
S3	90775	(h04b1/0475 g06n3/08 h04w88/08).cpc.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:25
S4	12807	455/501,63.1,67.13,114.3.ccls.	US-PGPUB;	OR	ON	2019/04/09

			USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			07:26
S5	102752	S3 or S4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:26
S6	2996	nonlinear with (pre-distort\$3 predistort\$3)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:27
S7	77	S6 same learn\$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:27
S8	17	S7 and correct\$3 near4 distortion	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:28
S9	4	S6 same learn\$4 near2 model	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 08:07
S10	9	S7 and learn\$4 near2 model	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 09:02
S11	3	"20170257051"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 09:07
S12	3	"20170257251"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT;	OR	ON	2019/04/09 09:07

			IBM_TDB			
S13	9	("20020181611" "20030184372" "20050195919" "20060133535" "20060240786" "20080106333" "20080265996" "20130121440" "6141390").PN. OR ("10075324").URPN.	US-PGPUB; USPAT; USOCR	OR	OFF	2019/04/09 09:09
S14	268827	(deployment standard) near3 communication	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:35
S15	9	S6 same S14	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:37
S16	402	(deployment near3 initial) with communication	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:41
S17	0	S6 and S16	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:41
S18	0	S16 same predistort\$3	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:41
S19	5	(distance near3 metric) same predistort\$3	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:49

10/ 4/ 2019 6:40:33 AM
C:\ Users\ strinh\ Documents\ EAST\ Workspaces\ 15955485 Predistort.wsp

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875				Application or Docket Number 15/955,485		Filing Date 04/17/2018		☐ To be Mailed	
ENTITY: ☐ LARGE ☒ SMALL ☐ MICRO									
APPLICATION AS FILED - PART I									
		(Column 1)	(Column 2)						
FOR		NUMBER FILED	NUMBER EXTRA		RATE (\$)		FEE (\$)		
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))		N/A	N/A		N/A				
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))		N/A	N/A		N/A				
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))		N/A	N/A		N/A				
TOTAL CLAIMS (37 CFR 1.16(i))		minus 20 = *		x \$50 =					
INDEPENDENT CLAIMS (37 CFR 1.16(h))		minus 3 = *		x \$230 =					
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))		If the specification and drawings exceed 100 sheets of paper, the application size fee due is \$310 (\$155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).							
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))									
* If the difference in column 1 is less than zero, enter "0" in column 2.					TOTAL				
APPLICATION AS AMENDED - PART II									
		(Column 1)		(Column 2)	(Column 3)				
AMENDMENT	07/15/2019	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE (\$)		ADDITIONAL FEE (\$)	
	Total (37 CFR 1.16(i))	* 24	Minus	** 24	= 0	x \$50 =		0	
	Independent (37 CFR 1.16(h))	* 4	Minus	*** 4	= 0	x \$230 =		0	
	☐ Application Size Fee (37 CFR 1.16(s))								
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))								
						TOTAL ADD'L FEE		0	
		(Column 1)		(Column 2)	(Column 3)				
AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA	RATE (\$)		ADDITIONAL FEE (\$)	
	Total (37 CFR 1.16(i))	*	Minus	**	=	x \$0 =			
	Independent (37 CFR 1.16(h))	*	Minus	***	=	x \$0 =			
	☐ Application Size Fee (37 CFR 1.16(s))								
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))								
						TOTAL ADD'L FEE			
* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.						SLIE			
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".						/JULIET MCMILLAN/			
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".									
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.									

This collection of information is required by 37 CFR 1.16. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor : Timothy James O'Shea Art Unit : 2649
Application No. : 15/955,485 Examiner : Sonny Trinh
Filed : April 17, 2018 Conf. No. : 1028
Title: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

Mail Stop Amendment

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

REPLY TO ACTION OF APRIL 15, 2019

Please consider the following reply.

Electronic Acknowledgement Receipt

EFS ID:	36584086
Application Number:	15955485
International Application Number:	
Confirmation Number:	1028
Title of Invention:	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM
First Named Inventor/Applicant Name:	Timothy James O'Shea
Customer Number:	26171
Filer:	Ayan Roy-Chowdhury/Sharon Allen
Filer Authorized By:	Ayan Roy-Chowdhury
Attorney Docket Number:	44837-0005001
Receipt Date:	15-JUL-2019
Filing Date:	17-APR-2018
Time Stamp:	15:08:18
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no
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File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		44837-0005001-Reply.pdf	112246	yes	9
			c7353127e216317beed389ad471d857713 7167bc		

	Multipart Description/PDF files in .zip description		
	Document Description	Start	End
	Applicant Arguments/Remarks Made in an Amendment	9	9
	Claims	2	8
	Amendment/Req. Reconsideration-After Non-Final Reject	1	1

Warnings:

Information:

Total Files Size (in bytes):	112246
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This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

First Named Inventor : Timothy James O'Shea
Application No. : 15/955,485
Filed : April 17, 2018
Page : 9 of 9

Attorney Docket: 44837-0005001

REMARKS

Applicant asks that all claims be allowed in view of the amendments and additions to the claims and the following remarks. No new matter has been added

Allowable Subject Matter

Applicant thanks the Office for the indication of allowable subject matter.

Claim Rejections - 35 USC §§ 102, 103

To advance prosecution, and without prejudice or disclaimer, Applicant has amended independent claims 1, 23 and 24 to incorporate the features of claim 4, which the Office has indicated as being allowable. Accordingly, independent claims 1, 23 and 24 are in condition for allowance, along with respective dependent claims, and such action is respectfully requested at the Office's earliest convenience.

Conclusion

It is believed that all of the pending issues have been addressed. Nothing in this reply should be construed as an intent to concede any issue with regard to any claim, except as specifically stated in this reply, and the amendment of any claim does not necessarily signify concession of unpatentability of the claim prior to its amendment.

Please apply any necessary charges or credits to Deposit Account 06 1050, referencing the above attorney docket number.

Respectfully submitted,

Date: July 15, 2019

/Ayan Roy-Chowdhury/
Ayan Roy-Chowdhury
Reg. No. 72,483

Customer Number 26171
Fish & Richardson P.C.
Telephone: +1 (202) 626-6428
Facsimile: (877) 769-7945

Amendments to Claims:

1. (Currently Amended) A method for correcting distortion of radio signals, the method comprising:

obtaining a transmit radio signal corresponding to an output of a transmitting radio signal processing system;

generating a pre-distorted radio signal by processing the transmit radio signal using a nonlinear pre-distortion machine learning model, wherein the nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to correct radio signal distortion;

obtaining a transmit output radio signal by processing the pre-distorted radio signal through the transmitting radio signal processing system; [[and]]

transmitting the transmit output radio signal to one or more radio receivers; and

updating the model parameters based on a distance metric computed between the transmit radio signal and a received signal that is obtained from the one or more radio receivers, the received signal corresponding to the transmit output radio signal that was transmitted to the one or more radio receivers.

2. (Original) The method of claim 1, wherein the model parameters are updated with values for a particular deployment scenario for a radio communication system upon initial deployment of the nonlinear pre-distortion machine learning model into the radio communication system.

3-4. (Cancelled)

5. (Currently Amended) The method of claim 1, wherein the model parameters are updated through a management process to minimize [[a]]the distance metric.

6. (Original) The method of claim 2, wherein the model parameters are updated depending on at least one environment condition within the radio communication system.

7. (Original) The method of claim 6, wherein the environment condition is one of: temperature, humidity, antenna impedance, power levels, or candidate transmit signal type.

8. (Original) The method of claim 2, wherein the particular deployment scenario comprises one of:

- sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in an inline mode;

- sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in a fault-tolerant subtractive mode;

- sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in an inline mode;

- sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in a fault-tolerant subtractive mode;

- sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates off a hardware chip and provides pre-distorted signals on the hardware chip or off the hardware chip;

- sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates on-chip and provides pre-distorted signals on a hardware chip;

- sending a radio transmission to a backhaul or satellite relay radio system and using feedback from one or more amplifiers to determine model parameters of the nonlinear pre-distortion machine learning model; or

- sending radio transmission to a system that includes interference cancellation.

9. (Original) The method of claim 1, wherein correcting distortion of radio signals includes correcting interference of radio signals.

10. (Original) A method for training a nonlinear pre-distortion model to correct distortion of radio signals, the method comprising:

obtaining a candidate transmit radio signal corresponding to output of a transmitting radio signal processing system;

processing the candidate transmit radio signal using a nonlinear pre-distortion machine learning model that executes using a set of model parameters to generate a pre-distorted candidate transmit radio signal, wherein the nonlinear pre-distortion machine learning model includes at least one nonlinear function to correct one or more of radio signal distortion or interference;

obtaining a received radio signal corresponding to input of a radio receiver by processing the pre-distorted candidate transmit radio signal using one or more sources of distortion or interference;

computing a distance metric between the candidate transmit radio signal and the received radio signal;

determining updated values for the set of model parameters of the nonlinear pre-distortion machine learning model that minimize the distance metric computed between the candidate transmit radio signal and the received radio signal to correct for one or more sources of alteration of the candidate transmit radio signal in the transmitting radio signal processing system; and

updating the values of the set of model parameters of the nonlinear pre-distortion machine learning model in order to train the nonlinear pre-distortion machine learning model.

11. (Original) The method of claim 10, wherein the model parameters are initially either randomly chosen or are seeded from a random distribution.

12. (Original) The method of claim 10, wherein the model parameters are optimized through a model optimization process to minimize radio signal distortion or interference.

13. (Original) The method of claim 10, wherein the distance metric is selected from one of: a mean squared error, absolute error, or computed between the candidate transmit radio signal and the received radio signal to form a quantitative measurement of an error value.

14. (Original) The method of claim 12, further comprising:

updating a type of model chosen for the nonlinear pre-distortion machine learning model in addition to updating the values of the set of model parameters of the nonlinear pre-distortion machine learning model using the model optimization process.

15. (Original) The method of claim 10, wherein initial values for the model parameters are computed using a distance metric in a pre-deployment environment for a specific device or type of device.

16. (Original) The method of claim 10 wherein the candidate transmit radio signal meets a desired use case for a particular deployment scenario.

17. (Original) The method of claim 16, wherein the particular deployment scenario comprises one of:

- sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in an inline mode;

- sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in a fault-tolerant subtractive mode;

- sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in an inline mode;

- sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in a fault-tolerant subtractive mode;

- sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates off a hardware chip and provides pre-distorted signals on the hardware chip or off the hardware chip;

- sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates on-chip and provides pre-distorted signals on a hardware chip;

- sending a radio transmission to a backhaul or satellite relay radio system and using feedback from one or more amplifiers to determine model parameters of the nonlinear pre-distortion machine learning model; or

sending radio transmission to a system that includes interference cancellation.

18. (Original) The method of claim 10, wherein the distance metric between the candidate transmit radio signal and the received radio signal minimizes cross-entropy towards a non-distorted target of a secondary trained classifier network trained to classify loss between a distorted and a non-distorted signal.

19. (Original) The method of claim 10, wherein the received radio signal is received after a wireless transmission from an antenna, or after a relay system receives, amplifies and retransmits the pre-distorted candidate transmit radio signal.

20. (Original) The method of claim 10, wherein the nonlinear pre-distortion machine learning model is one of a deep neural network, a convolutional neural network, a recurrent neural network, or a combination of different types of neural networks.

21. (Original) The method of claim 10, wherein determining updated values for the model parameters includes using Stochastic Gradient Descent style optimizers that iteratively minimize the distance metric based on an exact or approximate gradient of the distance metric with regard to the model parameters.

22. (Original) The method of claim 10, wherein correcting distortion of radio signals includes correcting interference of radio signals.

23. (Currently Amended) A system comprising:
one or more processors; and
one or more storage devices storing instructions that are operable, when executed on the one or more processors, to cause the one or more processors to:
obtain a transmit radio signal corresponding to an output of a transmitting radio signal processing system;
generate a pre-distorted radio signal by processing the transmit radio signal using a nonlinear pre-distortion machine learning model, wherein the nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to

correct radio signal distortion;

obtain a transmit output radio signal by processing the pre-distorted radio signal through the transmitting radio signal processing system; [[and]]

transmit the transmit output radio signal to one or more radio receivers; and
update the model parameters based on a distance metric computed between the transmit radio signal and a received signal that is obtained from the one or more radio receivers, the received signal corresponding to the transmit output radio signal that was transmitted to the one or more radio receivers.

24. (Currently Amended) One or more non-transitory computer-readable storage ~~media~~ ~~mediums~~ comprising instructions stored thereon that are executable by a processing device and upon such execution cause the processing device to:

obtain a transmit radio signal corresponding to an output of a transmitting radio signal processing system;

generate a pre-distorted radio signal by processing the transmit radio signal using a nonlinear pre-distortion machine learning model, wherein the nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to correct at least one of radio signal distortion or interference;

obtain a transmit output radio signal by processing the pre-distorted radio signal through the transmitting radio signal processing system; [[and]]

transmit the transmit output radio signal to one or more radio receivers; and
update the model parameters based on a distance metric computed between the transmit radio signal and a received signal that is obtained from the one or more radio receivers, the received signal corresponding to the transmit output radio signal that was transmitted to the one or more radio receivers.

25. (New) The one or more non-transitory computer-readable storage media of claim 24, wherein the model parameters are updated with values for a particular deployment scenario for a radio communication system upon initial deployment of the nonlinear pre-distortion machine learning model into the radio communication system.

First Named Inventor : Timothy James O'Shea
Application No. : 15/955,485
Filed : April 17, 2018
Page : 8 of 9

Attorney Docket: 44837-0005001

26. (New) The system of claim 23, wherein the model parameters are updated with values for a particular deployment scenario for a radio communication system upon initial deployment of the nonlinear pre-distortion machine learning model into the radio communication system.



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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
15/955,485	04/17/2018	Timothy James O'Shea	44837-0005001	1028
26171	7590	04/15/2019		
FISH & RICHARDSON P.C. (DC)			EXAMINER	
P.O. BOX 1022			TRINH, SONNY	
MINNEAPOLIS, MN 55440-1022				
			ART UNIT	PAPER NUMBER
			2649	
			NOTIFICATION DATE	DELIVERY MODE
			04/15/2019	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

PATDOCTC@fr.com

DETAILED ACTION

Notice of Pre-AIA or AIA Status

1. The present application, filed on or after March 16, 2013, is being examined under the first inventor to file provisions of the AIA.

Claim Rejections - 35 USC § 102

2. In the event the determination of the status of the application as subject to AIA 35 U.S.C. 102 and 103 (or as subject to pre-AIA 35 U.S.C. 102 and 103) is incorrect, any correction of the statutory basis for the rejection will not be considered a new ground of rejection if the prior art relied upon, and the rationale supporting the rejection, would be the same under either status.

3. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless –

(a)(1) the claimed invention was patented, described in a printed publication, or in public use, on sale or otherwise available to the public before the effective filing date of the claimed invention.

4. **Claims 1, 3, 23, 24** are rejected under 35 U.S.C. 102(a)(1) as being anticipated by Lozhkin (US 9,397,619).

Regarding **claim 1**, with reference to figure 1 and corresponding text, Lozhkin discloses a method for correcting distortion of radio signals (see background of the

invention in column 1 lines 22-67), the method comprising: obtaining a transmit radio signal corresponding to an output of a transmitting radio signal processing system (figure 1, the output of the power amplifier 2 is feedback to the distortion compensation apparatus 10); generating a pre-distorted radio signal by processing the transmit radio signal using a nonlinear pre-distortion machine learning model (figure 1, learner 13 and column 1 lines 46-58), wherein the nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to correct radio signal distortion ('the learner updates the compensation coefficient on the basis of the distorted feedback signal', see abstract); obtaining a transmit output radio signal by processing the pre-distorted radio signal through the transmitting radio signal processing system (figure 1, "...The power amplifier 2 and the distortion compensation apparatus 10 are included in, for example, a radio transmitter which transmits a radio signal...", column 3 lines 61-65); and transmitting the transmit output radio signal to one or more radio receivers (the signal is then transmitted to the radio receiver 200 of figure 2, column 5, lines 45-51).

As to **claim 3**, Lozhkin further discloses the method of claim 1, further comprising: receiving a received signal from one or more radio receivers corresponding to the transmit output radio signal that was transmitted to the one or more radio receivers (figure 2 shows at least one receiver 200).

As to **claims 23-24**, these claims are the corresponding system and computer program for performing the method of claim 1 and are therefore rejected for the same reasons as in the rejection of claim 1 above. It is noted that computer instructions is inherent in Lozhkin's invention and figures 1, 4-5 depict different system for performing the method steps of claim 1.

Claim Rejections - 35 USC § 103

5. The following is a quotation of 35 U.S.C. 103 which forms the basis for all obviousness rejections set forth in this Office action:

A patent for a claimed invention may not be obtained, notwithstanding that the claimed invention is not identically disclosed as set forth in section 102 of this title, if the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art to which the claimed invention pertains. Patentability shall not be negated by the manner in which the invention was made.

6. **Claims 5, 9** are rejected under 35 U.S.C. 103 as being unpatentable over Lozhkin (US 9,397,619) in view of Braithwaite (US 7,289,773).

Regarding **claim 5**, Lozhkin discloses the method of claim 1 but does not disclose wherein the model parameters are updated through a management process to minimize a distance metric.

In an analogous art, Braithwaite teaches a Digital transmitter system employing self-generating predistortion parameter lists and adaptive controller (title). Braithwaite further teaches the model parameters are updated through a management process to minimize a distance metric (claims 6, 14, 26, 32, 39, 'the least distance is selected', column 7 lines 4-12, column 12 lines 21-45).

Therefore, it would have been obvious to one of ordinary skill in the art before the effective the filling date of claimed invention (AIA) to modify the above teaching of Braithwaite to the method of Lozhkin in order to further reduce the distortion.

As to **claim 9**, Lozhkin discloses the method of claim 1 but does not explicitly discloses wherein correcting distortion of radio signals includes correcting interference of radio signals. Braithwaite discloses the interference distortion is corrected (column 2, lines 13-15, column 5, lines 1-6).

Therefore, it would have been obvious to one of ordinary skill in the art before the effective the filling date of claimed invention (AIA) to modify the above teaching of Braithwaite to the method of Lozhkin in order to reduce the distortion to linearize the transmitter.

Allowable Subject Matter

7. Claims 2, 4, 6-8 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.

Regarding **claim 2**, the prior art of record fail to disclose or render obvious the method of claim 1, wherein the model parameters are updated with values for a particular deployment scenario for a radio communication system upon initial deployment of the nonlinear pre-distortion machine learning model into the radio communication system.

Claims 6-7 depend on claim 2 and are therefore objected for the same reasons.

Regarding **claim 4**, the prior art of record fail to disclose or render obvious the method of claim 3, wherein the model parameters are updated based on a distance metric computed between the transmit radio signal corresponding to output of a transmitting radio signal processing system and the received signal of the one or more radio receivers.

Regarding **claim 8**, the prior art of record fail to disclose or render obvious the method of claim 2, wherein the particular deployment scenario comprises one of: sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion

machine learning model inside a tower mounted amplifier in an inline mode; sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in a fault-tolerant subtractive mode; sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in an inline mode; sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in a fault-tolerant subtractive mode; sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates off a hardware chip and provides pre-distorted signals on the hardware chip or off the hardware chip; sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates on-chip and provides pre-distorted signals on a hardware chip; sending a radio transmission to a backhaul or satellite relay radio system and using feedback from one or more amplifiers to determine model parameters of the nonlinear pre-distortion machine learning model; or sending radio transmission to a system that includes interference cancellation.

Allowable Subject Matter

8. **Claims 10-22** are allowed.

The following is an examiner's statement of reasons for allowance:

Regarding **claim 10**, the prior art of record fail to disclose or render obvious a method for training a nonlinear pre-distortion model to correct distortion of radio signals,

the method comprising: obtaining a candidate transmit radio signal corresponding to output of a transmitting radio signal processing system; processing the candidate transmit radio signal using a nonlinear pre-distortion machine learning model that executes using a set of model parameters to generate a pre- distorted candidate transmit radio signal, wherein the nonlinear pre-distortion machine learning model includes at least one nonlinear function to correct one or more of radio signal distortion or interference; obtaining a received radio signal corresponding to input of a radio receiver by processing the pre-distorted candidate transmit radio signal using one or more sources of distortion or interference; computing a distance metric between the candidate transmit radio signal and the received radio signal; determining updated values for the set of model parameters of the nonlinear pre- distortion machine learning model that minimize the distance metric computed between the candidate transmit radio signal and the received radio signal to correct for one or more sources of alteration of the candidate transmit radio signal in the transmitting radio signal processing system; and updating the values of the set of model parameters of the nonlinear pre-distortion machine learning model in order to train the nonlinear pre-distortion machine learning model.

Claims 11-22 are also allowed by virtue of their dependency on claim 10.

Conclusion

Any inquiry concerning this communication or earlier communications from the examiner should be directed to SONNY TRINH whose telephone number is (571)272-7927 (M-F from 7:00 Am to 3:30 Pm).

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Ed URBAN can be reached on 571-272-7899. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see <http://pair-direct.uspto.gov>. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/SONNY TRINH/
Primary Examiner, Art Unit 2649

4/11/19

<i>Notice of References Cited</i>	Application/Control No. 15/955,485		Applicant(s)/Patent Under Reexamination O'Shea et al.	
	Examiner SONNY TRINH		Art Unit 2649	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	CPC Classification	US Classification
*	A	US-10075324-B2	09-2018	Zhao; Yanqing	H03F1/3247	1/1
*	B	US-6141390-A	10-2000	Cova; Armando	H03F1/3247	330/149
*	C	US-9397619-B2	07-2016	Lozhkin; Alexander Nikolaevich	H03F1/3247	1/1
*	D	US-7372918-B2	05-2008	Muller; Jan-Erik	H03F1/3247	330/127
*	E	US-7289773-B2	10-2007	Braithwaite; Richard Neil	H03F1/3235	375/297
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	CPC Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

<i>Search Notes</i> 	Application/Control No. 15/955,485	Applicant(s)/Patent Under Reexamination O'Shea et al.
	Examiner SONNY TRINH	Art Unit 2649

CPC - Searched*		
Symbol	Date	Examiner
h04b1/0475 g06n3/08 h04w88/08	04/09/2019	ST

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner
455	501,63.1,67.13,114.3	04/09/2019	ST

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	Date	Examiner
EAST, CPC, Inventors	04/09/2019	ST

Interference Search			
US Class/CPC Symbol	US Subclass/CPC Group	Date	Examiner

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<i>Index of Claims</i> 	Application/Control No. 15/955,485	Applicant(s)/Patent Under Reexamination O'Shea et al.
	Examiner SONNY TRINH	Art Unit 2649

✓	Rejected	-	Cancelled	N	Non-Elected	A	Appeal
=	Allowed	÷	Restricted	I	Interference	O	Objected

CLAIMS										
☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47										
CLAIM			DATE							
Final	Original	04/09/2019								
	1	✓								
	2	○								
	3	✓								
	4	○								
	5	✓								
	6	○								
	7	○								
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	18	=								
	19	=								
	20	=								
	21	=								
	22	=								
	23	✓								
	24	✓								

Bibliographic Data

Application No: 15/955,485

Foreign Priority claimed: ☐ Yes ☒ No

35 USC 119 (a-d) conditions met: ☐ Yes ☒ No ☐ Met After Allowance

Verified and Acknowledged:

/SONNY TRINH/

Examiner's Signature

Initials

Title:

MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION
SYSTEM

FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
04/17/2018	455	2649	44837-0005001
RULE			

APPLICANTS

DeepSig Inc., Arlington, VA, UNITED STATES

INVENTORS

Timothy James O'Shea Arlington, VA, UNITED STATES

James Shea Arlington, VA, UNITED STATES

CONTINUING DATA

This application has PRO of 62486200 04/17/2017

FOREIGN APPLICATIONS

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05/15/2018

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STATE OR COUNTRY

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ADDRESS

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P.O. BOX 1022

MINNEAPOLIS, MN 55440-1022

UNITED STATES

FILING FEE RECEIVED

\$1,295

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	0	15/955485	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:16
L2	162	((("O'SHEA") near3 ("Timothy")) OR (("SHEA") near3 ("James"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	OFF	2019/04/09 07:16
L3	90775	(h04b1/0475 g06n3/08 h04w88/08).cpc.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:25
L4	12807	455/501,63.1,67.13,114.3.ccls.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:26
L5	102752	3 or 4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:26
L6	2996	nonlinear with (pre-distort\$3 predistort\$3)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:27
L7	77	6 same learn\$4	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 07:27
L8	17	7 and correct\$3 near4 distortion	US-PGPUB; USPAT; USOCR;	OR	ON	2019/04/09 07:28

			FPRS; EPO; JPO; DERWENT; IBM_TDB			
L9	4	6 same learn\$4 near2 model	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 08:07
L10	9	7 and learn\$4 near2 model	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 09:02
L11	3	"20170257051"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 09:07
L12	3	"20170257251"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 09:07
L13	9	("20020181611" "20030184372" "20050195919" "20060133535" "20060240786" "20080106333" "20080265996" "20130121440" "6141390").PN. OR ("10075324").URPN.	US-PGPUB; USPAT; USOCR	OR	OFF	2019/04/09 09:09
L14	268827	(deployment standard) near3 communication	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:35
L15	9	6 same 14	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:37
L16	402	(deployment near3 initial) with communication	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:41
L17	0	6 and 16	US-PGPUB; USPAT;	OR	ON	2019/04/09 10:41

			USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB			
L18	0	16 same predistort\$3	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:41
L19	5	(distance near3 metric) same predistort\$3	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2019/04/09 10:49

EAST Search History (Interference)

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4/ 9/ 2019 12:51:51 PM



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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
15/955,485	04/17/2018	Timothy James O'Shea	44837-0005001

CONFIRMATION NO. 1028

INFORMAL NOTICE



26171
FISH & RICHARDSON P.C. (DC)
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022

Date Mailed: 05/16/2018

INFORMATIONAL NOTICE TO APPLICANT

Applicant is notified that the above-identified application contains the deficiencies noted below. No period for reply is set forth in this notice for correction of these deficiencies. However, if a deficiency relates to the inventor's oath or declaration, the applicant must file an oath or declaration in compliance with 37 CFR 1.63, or a substitute statement in compliance with 37 CFR 1.64, executed by or with respect to each actual inventor no later than the expiration of the time period set in the "Notice of Allowability" to avoid abandonment. See 37 CFR 1.53(f).

The item(s) indicated below are also required and should be submitted with any reply to this notice to avoid further processing delays.

- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
Timothy James O'Shea
James Shea

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at (571) 272-4000 or (571) 272-4200 or 1-888-786-0101.

/afessechaye/

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number
15/955,485

APPLICATION AS FILED - PART I

(Column 1)

(Column 2)

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

FOR	NUMBER FILED	NUMBER EXTRA
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A
SEARCH FEE (37 CFR 1.16(k), (l), or (m))	N/A	N/A
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A
TOTAL CLAIMS (37 CFR 1.16(i))	24 minus 20 =	* 4
INDEPENDENT CLAIMS (37 CFR 1.16(h))	4 minus 3 =	* 1
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is \$310 (\$155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).	
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))		

RATE(\$)	FEE(\$)
N/A	75
N/A	330
N/A	380
x 50 =	200
x 230 =	230
	0.00
	0.00
TOTAL	1215

OR

RATE(\$)	FEE(\$)
N/A	
N/A	
N/A	
TOTAL	

* If the difference in column 1 is less than zero, enter "0" in column 2.

APPLICATION AS AMENDED - PART II

(Column 1)

(Column 2)

(Column 3)

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

AMENDMENT A		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
	Total (37 CFR 1.16(i))	*	Minus	**	=
	Independent (37 CFR 1.16(h))	*	Minus	***	=
	Application Size Fee (37 CFR 1.16(s))				
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))				

RATE(\$)	ADDITIONAL FEE(\$)
x =	
x =	
TOTAL ADD'L FEE	

OR

RATE(\$)	ADDITIONAL FEE(\$)
x =	
x =	
TOTAL ADD'L FEE	

(Column 1)

(Column 2)

(Column 3)

AMENDMENT B		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
	Total (37 CFR 1.16(i))	*	Minus	**	=
	Independent (37 CFR 1.16(h))	*	Minus	***	=
	Application Size Fee (37 CFR 1.16(s))				
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))				

RATE(\$)	ADDITIONAL FEE(\$)
x =	
x =	
TOTAL ADD'L FEE	

OR

RATE(\$)	ADDITIONAL FEE(\$)
x =	
x =	
TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
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Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
15/955,485	04/17/2018	2842	1295	44837-0005001	24	4

CONFIRMATION NO. 1028

FILING RECEIPT

26171
FISH & RICHARDSON P.C. (DC)
P.O. BOX 1022
MINNEAPOLIS, MN 55440-1022



Date Mailed: 05/16/2018

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Timothy James O'Shea, Arlington, VA;
James Shea, Arlington, VA;

Applicant(s)

DeepSig Inc., Arlington, VA

Power of Attorney: None

Domestic Priority data as claimed by applicant

This appln claims benefit of 62/486,200 04/17/2017

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see <http://www.uspto.gov> for more information.) - None.

Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 05/15/2018

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 15/955,485**

Projected Publication Date: Request for Non-Publication Acknowledged

Non-Publication Request: Yes

Early Publication Request: No

**** SMALL ENTITY ****

Title

MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

Preliminary Class

330

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at <http://www.uspto.gov/web/offices/pac/doc/general/index.html>.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, <http://www.stopfakes.gov>. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER
Title 35, United States Code, Section 184
Title 37, Code of Federal Regulations, 5.11 & 5.15

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The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign Assets Control, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

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FISH & RICHARDSON

April 17, 2018

Attorney Docket No.: 44837-0005001

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Street Address
Fish & Richardson P.C.
901 15th Street, N.W.
7th Floor
Washington, DC 20005

Mail Address
P.O. Box 1022
Minneapolis, MN 55440-1022
202 783 5070 main
877 769 7945 fax

Presented for filing is a new patent application claiming priority from a provisional patent application of:

Inventor(s): TIMOTHY JAMES O'SHEA and JAMES SHEA

Title: MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

This application claims the benefit of the filing date and priority of the following application(s):

<u>Application No.</u>	<u>Country or Region</u>	<u>Filing Date</u>
62/486,200	United States	April 17, 2017

Enclosed are the following papers, including those required to receive a filing date under 37 CFR 1.53(b):

	<u>Pages</u>
Application Data Sheet	8
Specification	20
Claims	6
Abstract	1
Drawing(s)	12
Declaration	[To be Filed at a Later Date]

Enclosures:

— Nonpublication-Request, 1 page.

The applicant claims small entity status under 37 CFR 1.27.

Basic Filing Fee	\$75
Search Fee	\$330
Examination Fee	\$380
Total Claims 24 over 20	4 x \$50
Independent Claims 4 over 3	1 x \$230
Fee for Multiple Dependent claims	\$0
Application size fee for each 50 pages over 100	
Total Sheets: $39 \times .75 - 100/50 = 0x$	\$0
Surcharge for late filing fee, for oath or declaration	\$80
Total Filing fee	\$1295



Commissioner for Patents
April 17, 2018

The total filing fee is being paid concurrently on the Electronic Filing System (EFS) by deposit account authorization. Apply any other required fees or any credits to Deposit Account No. 06-1050, referencing the attorney docket number shown above.

I hereby authorize the USPTO to communicate in response to email communications from the undersigned and practitioners under Customer No. 26171 in accordance with 37 CFR 1.33 and 37 CFR 1.34 concerning any subject matter of this application via email. I understand that a copy of these communications will be made of record in the application file. (MPEP 502.03).

If this application is considered to be incomplete, or if a telephone conference would otherwise be helpful, call the undersigned at +1 (202) 626-6428.

Send all correspondence to:

26171
Customer Number

Respectfully submitted,

/Stephanie D. Grosvenor/

Stephanie D. Grosvenor
Registration No. 67,592

SDG/sxw

Enclosures

41328195.doc

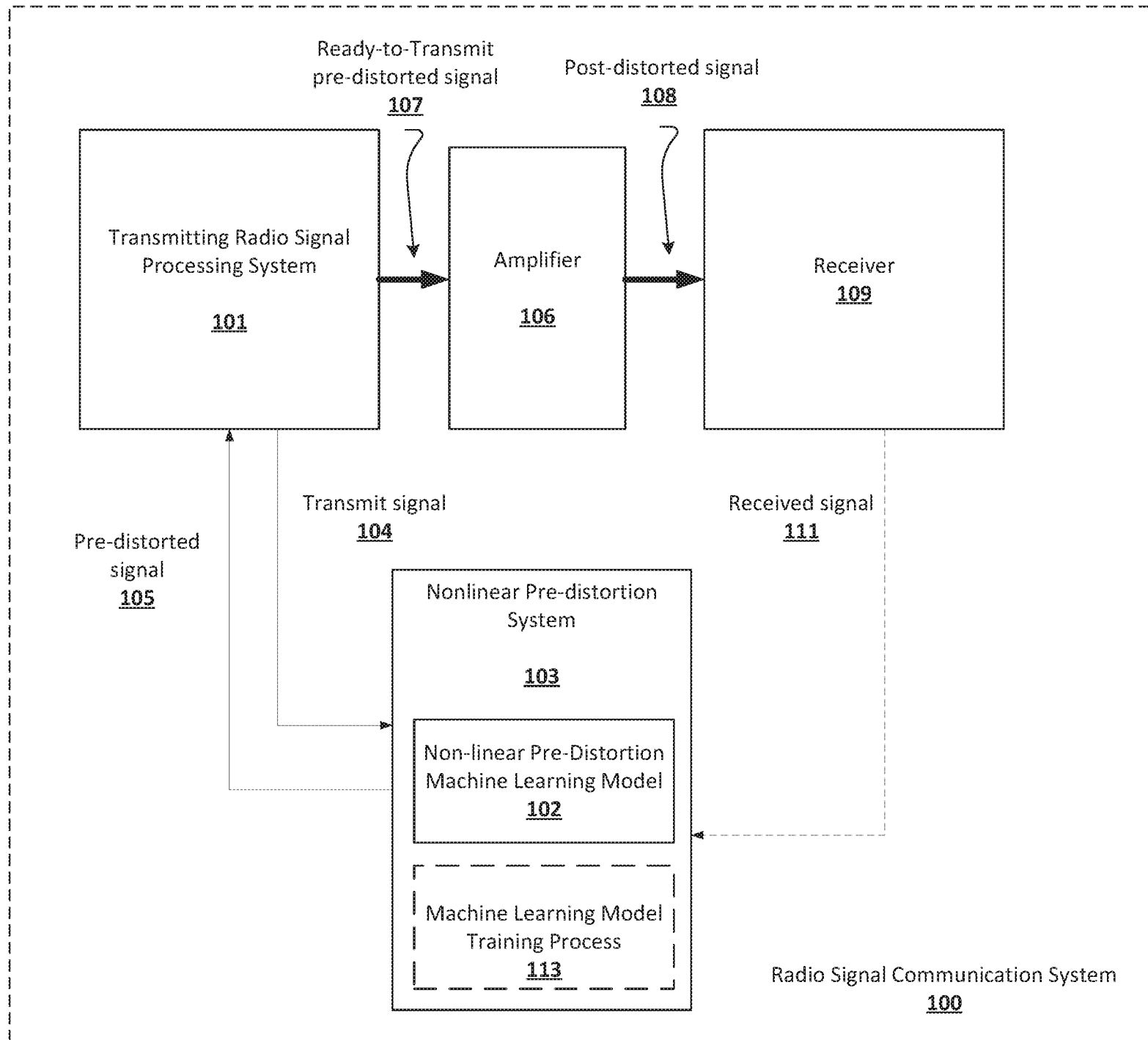


FIG. 1

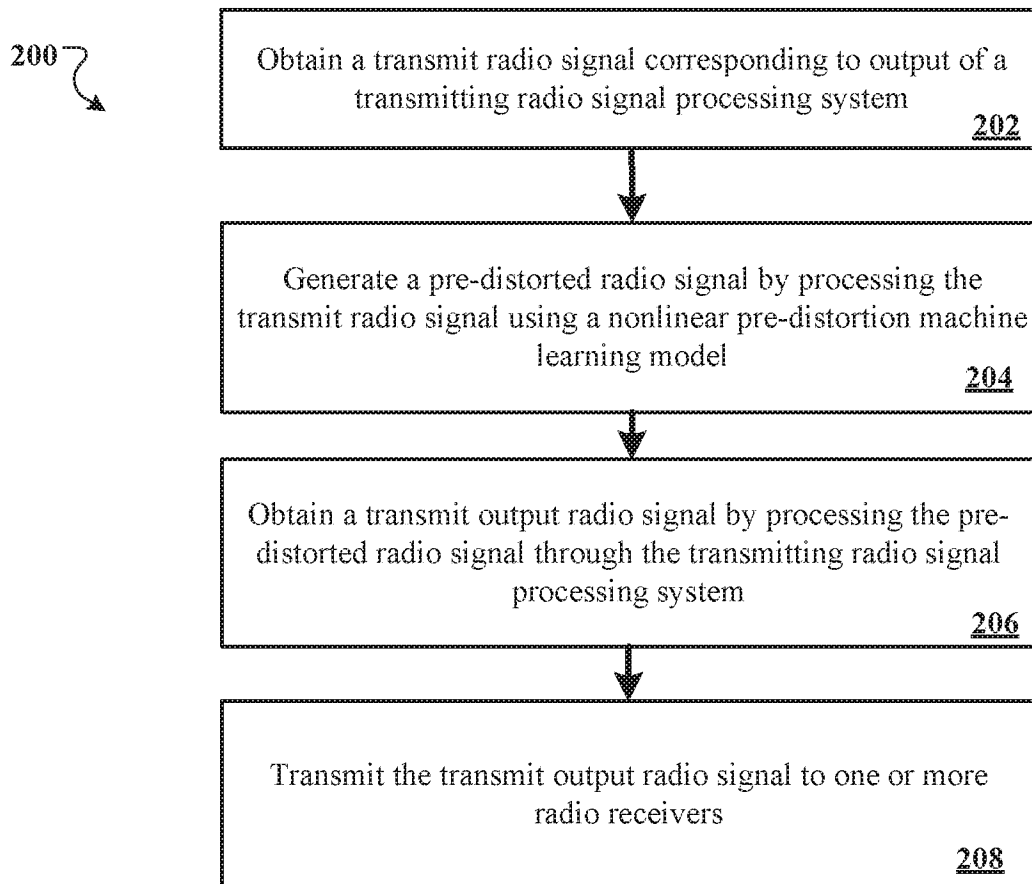


FIG. 2

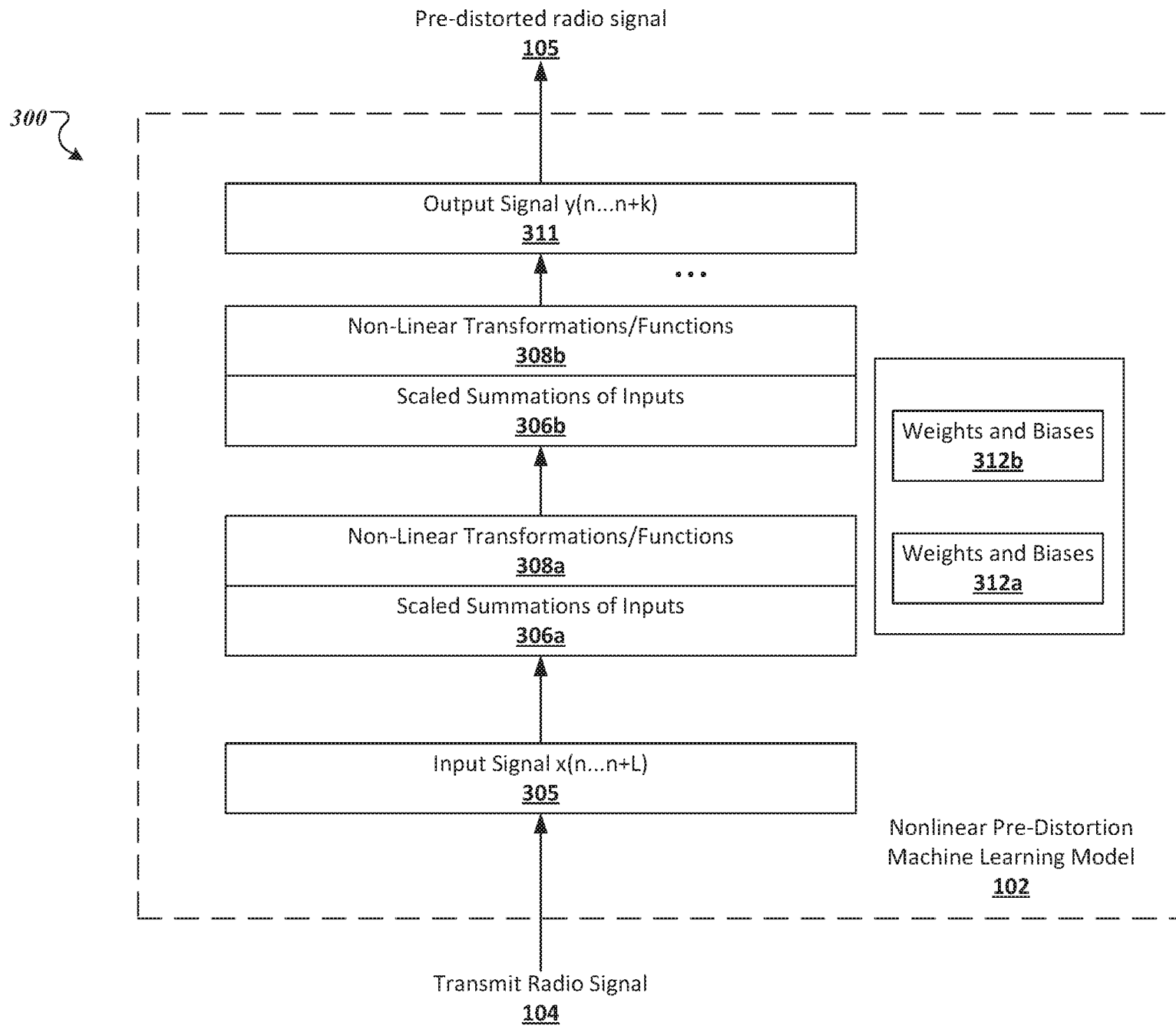


FIG. 3

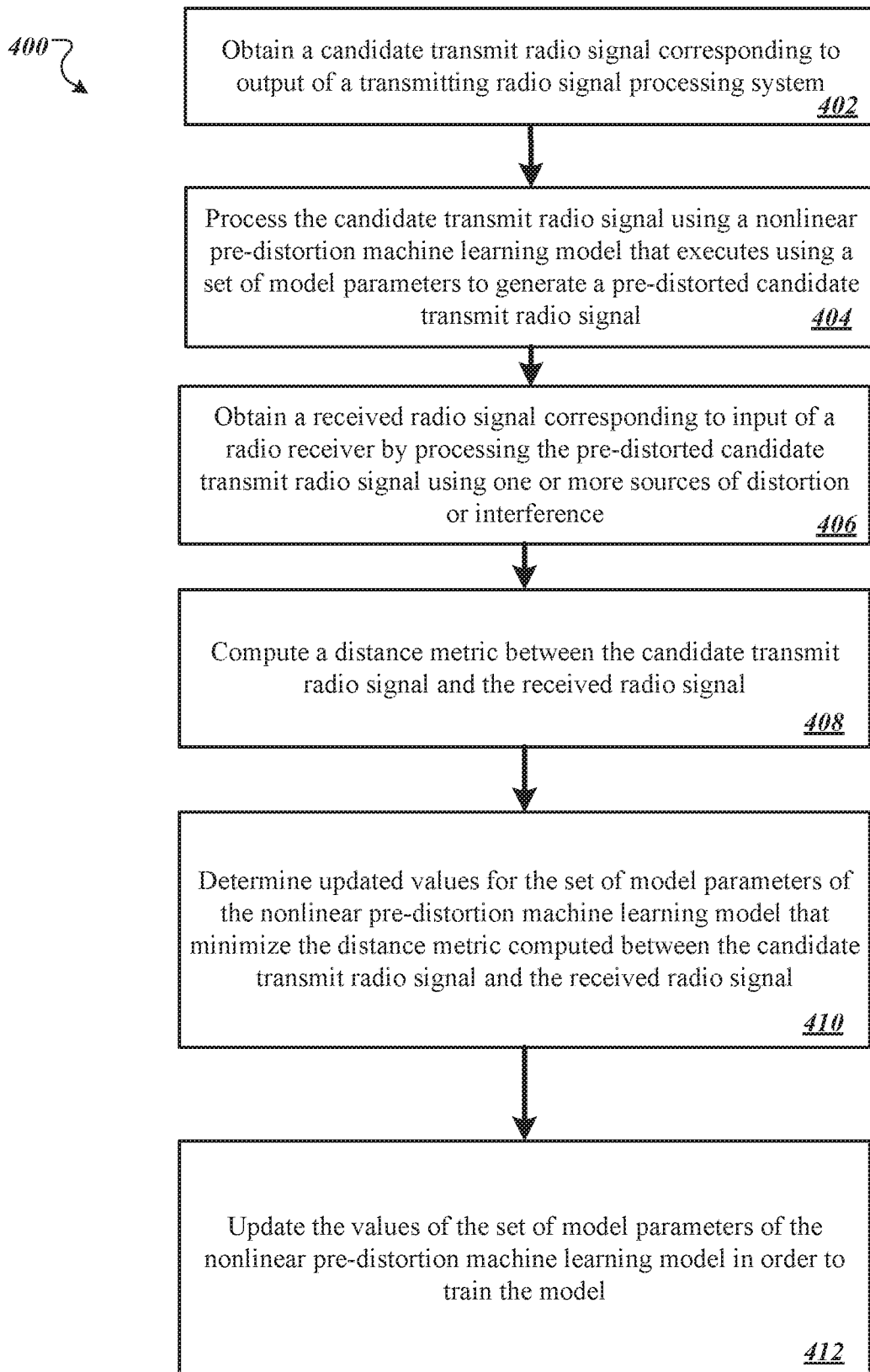


FIG. 4

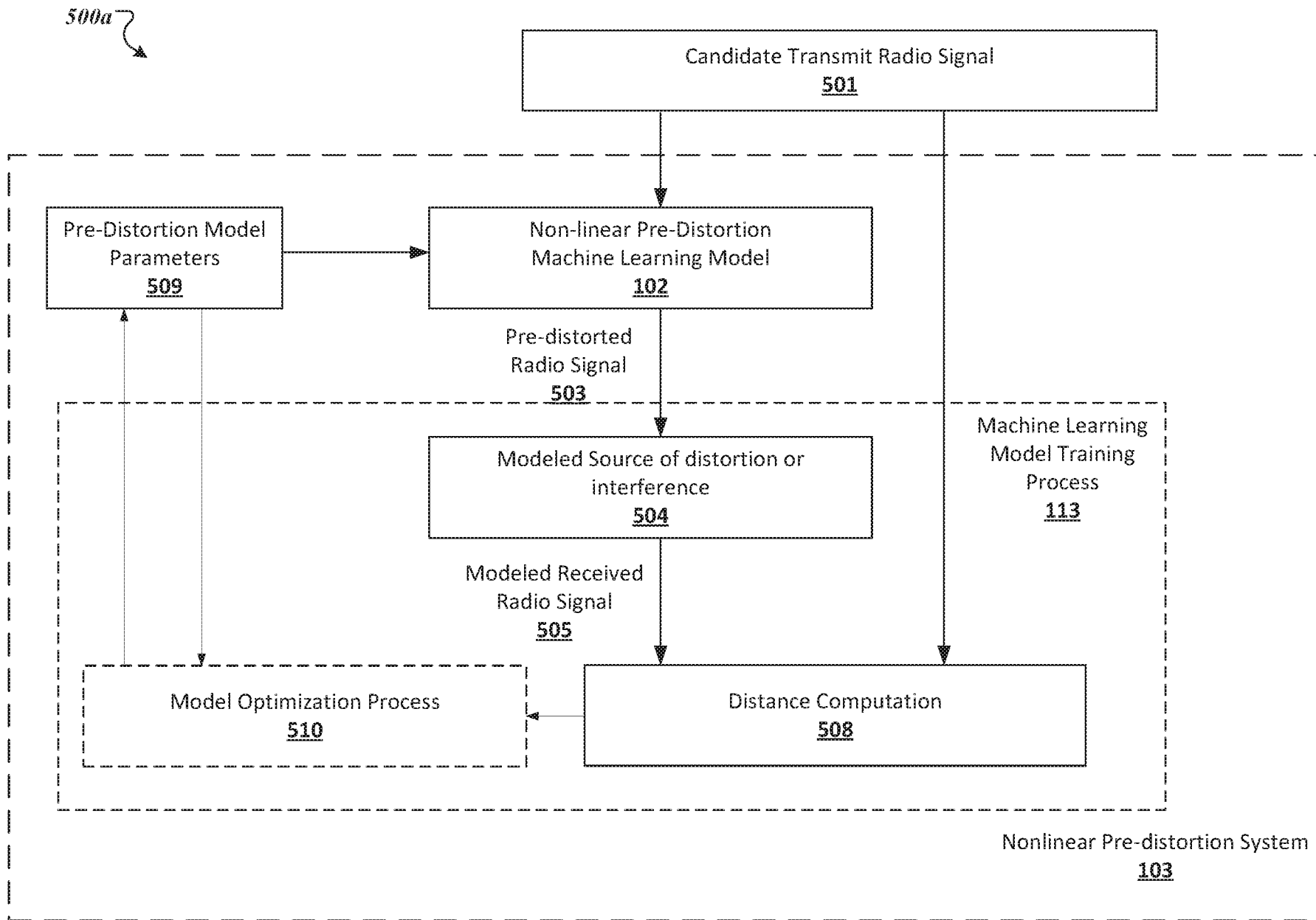


FIG. 5A

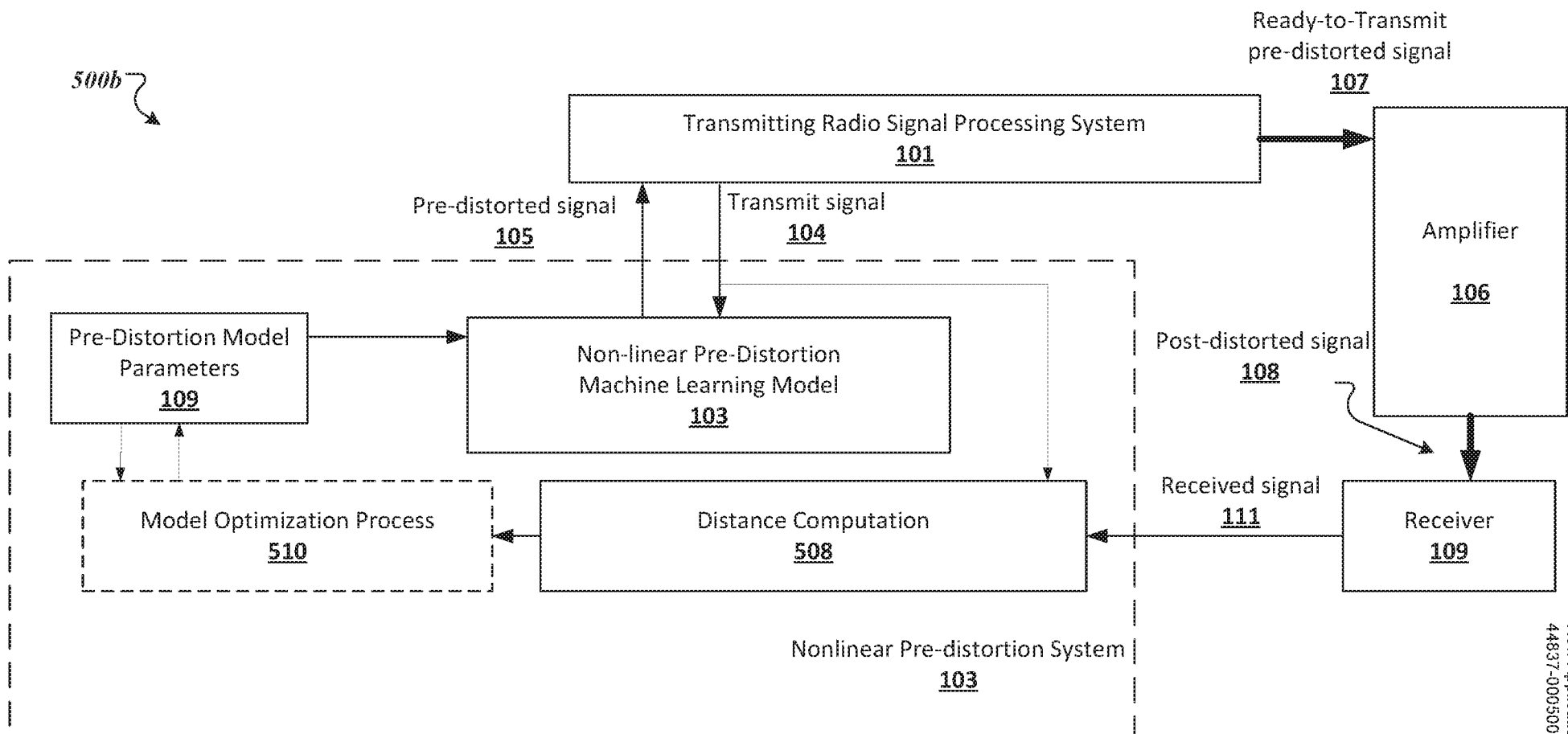


FIG. 5B

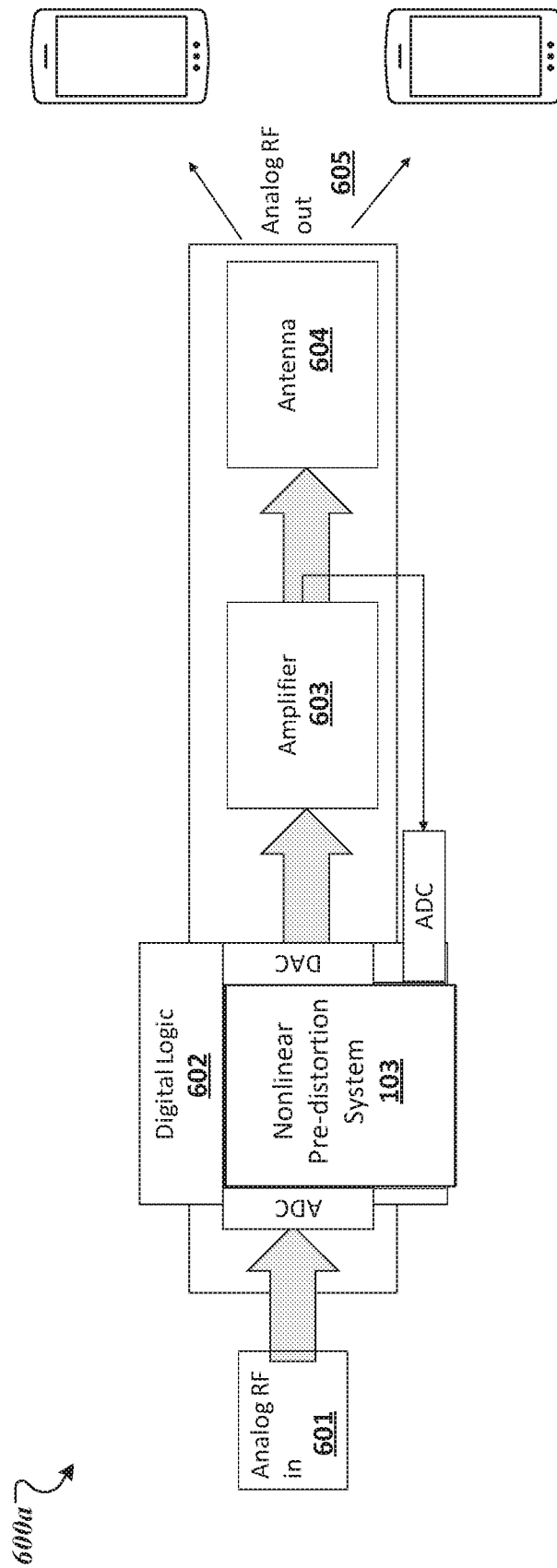


FIG. 6A

500b

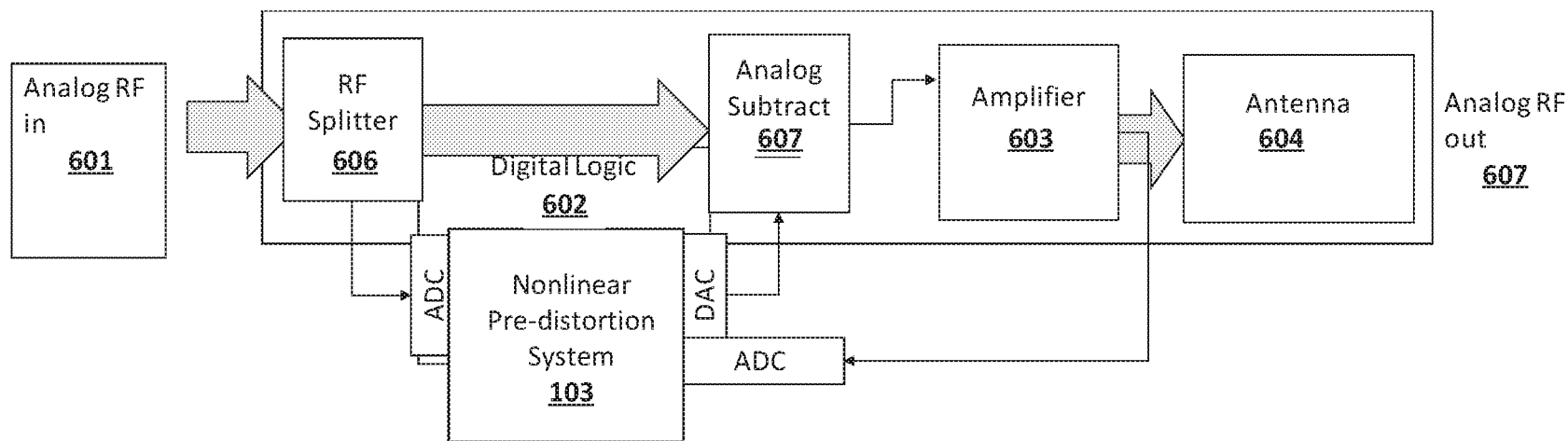


FIG. 6B

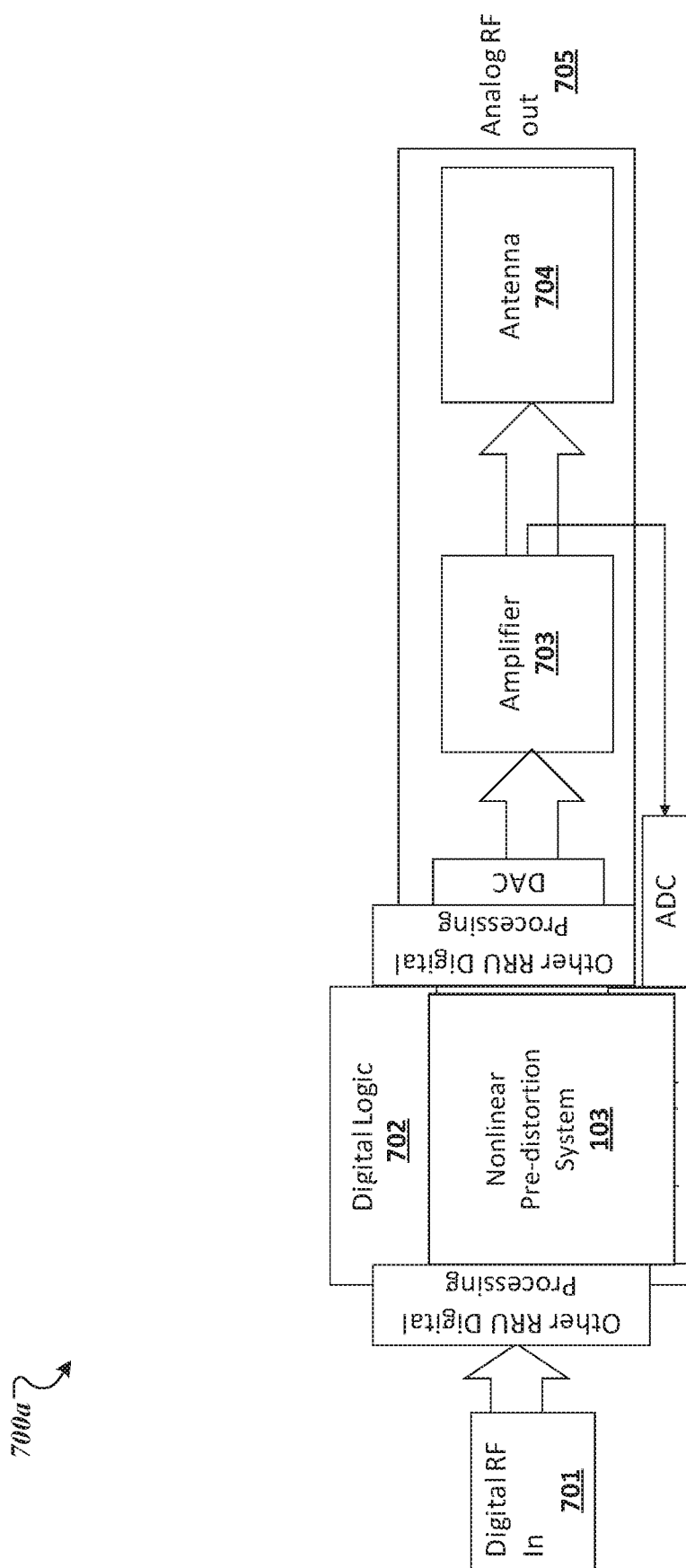


FIG. 7A

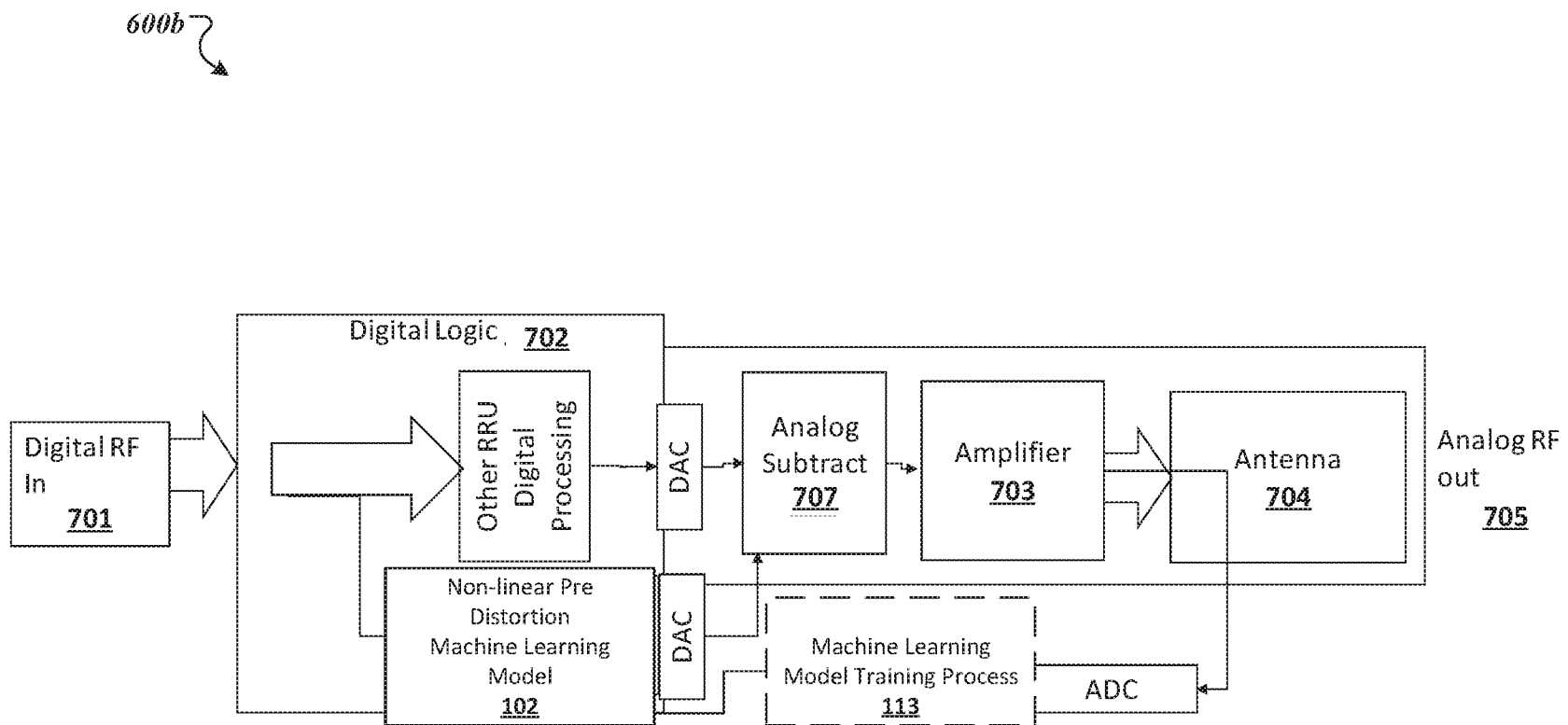


FIG. 7B

800

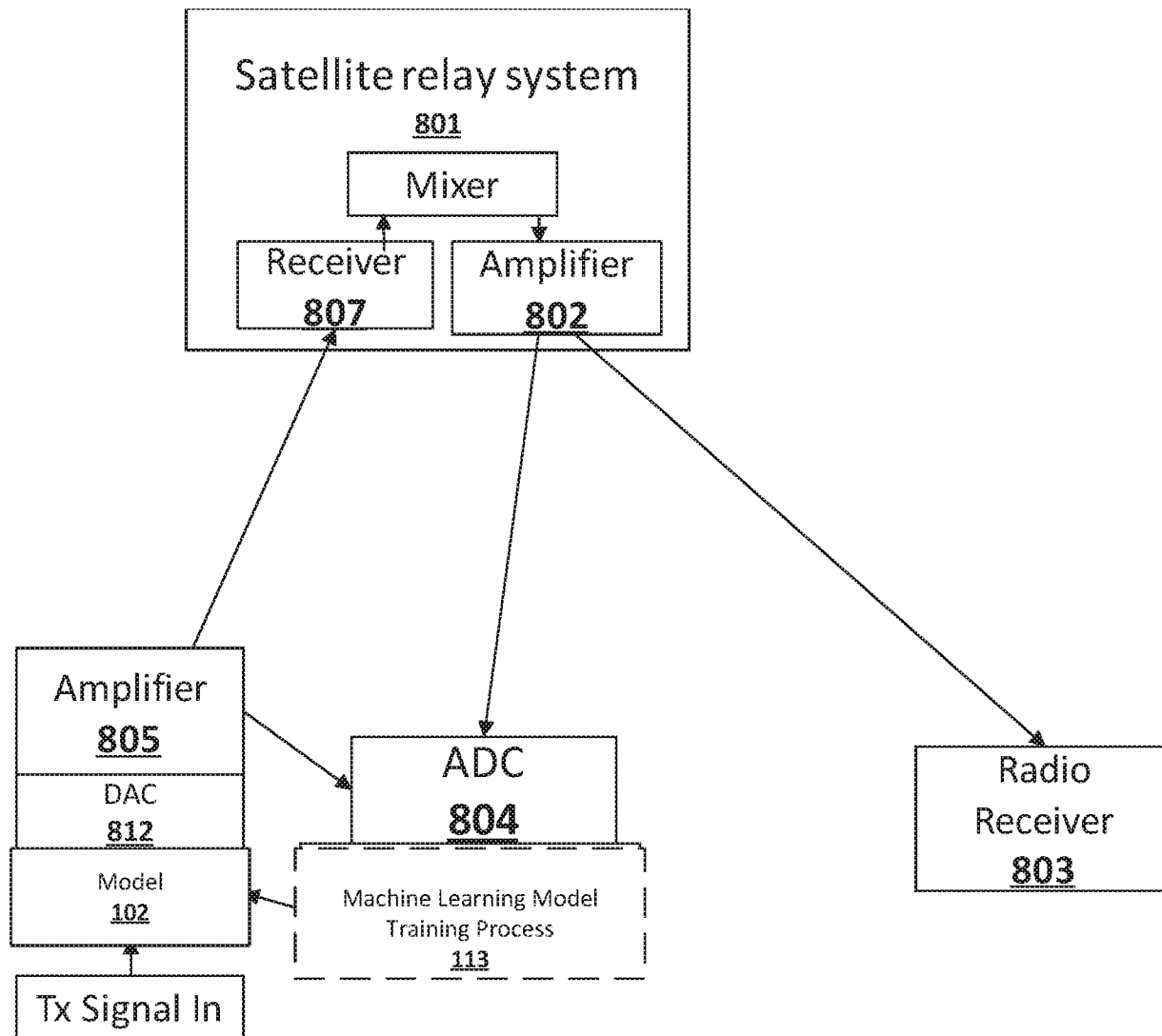


FIG. 8

NONPUBLICATION REQUEST UNDER 35 U.S.C. 122(b)(2)(B)(i)	First Named Inventor		Timothy James O'Shea
	Title	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM	
	Attorney Docket Number		44837-0005001

I hereby certify that the invention disclosed in the attached application **has not and will not be** the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

I hereby request that the attached application not be published under 35 U.S.C. 122(b).

/Stephanie D. Grosvenor/

Signature

April 17, 2018

Date

Stephanie D. Grosvenor

Typed or printed name

67,592

Registration Number, if applicable

+1 (202) 626-6428

Telephone Number

This request must be signed in compliance with 37 CFR 1.33(b) and submitted with the application **upon filing**.

Applicant may rescind this nonpublication request at any time. If applicant rescinds a request that an application not be published under 35 U.S.C. 122(b), the application will be scheduled for publication at eighteen months from the earliest claimed filing date for which a benefit is claimed.

If applicant subsequently files an application directed to the invention disclosed in the attached application in another country, or under a multilateral international agreement, that requires publication of applications eighteen months after filing, the applicant **must** notify the United States Patent and Trademark Office of such filing within forty-five (45) days after the date of the filing of such foreign or international application. **Failure to do so will result in abandonment of this application (35 U.S.C. 122(b)(2)(B)(iii)).**

This collection of information is required by 37 CFR 1.213(a). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 6 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Electronic Patent Application Fee Transmittal				
Application Number:				
Filing Date:				
Title of Invention:		MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM		
First Named Inventor/Applicant Name:		Timothy James O'Shea		
Filer:		STEPHANIE D. GROSVENOR/Sharon M. Allen		
Attorney Docket Number:		44837-0005001		
Filed as Small Entity				
Filing Fees for Utility under 35 USC 111(a)				
Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Basic Filing:				
UTILITY FILING FEE (ELECTRONIC FILING)	4011	1	75	75
UTILITY SEARCH FEE	2111	1	330	330
UTILITY EXAMINATION FEE	2311	1	380	380
Pages:				
Claims:				
CLAIMS IN EXCESS OF 20	2202	4	50	200
INDEPENDENT CLAIMS IN EXCESS OF 3	2201	1	230	230
Miscellaneous-Filing:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
LATE FILING FEE FOR OATH OR DECLARATION	2051	1	80	80
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
Total in USD (\$)				1295

Electronic Acknowledgement Receipt

EFS ID:	32365429
Application Number:	15955485
International Application Number:	
Confirmation Number:	1028
Title of Invention:	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM
First Named Inventor/Applicant Name:	Timothy James O'Shea
Customer Number:	26171
Filer:	STEPHANIE D. GROSVENOR/Susan Williams
Filer Authorized By:	STEPHANIE D. GROSVENOR
Attorney Docket Number:	44837-0005001
Receipt Date:	17-APR-2018
Filing Date:	
Time Stamp:	18:15:06
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	DA
Payment was successfully received in RAM	\$ 1295
RAM confirmation Number	041818INTEFSW00004875061050
Deposit Account	
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

File Listing:					
Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Application Data Sheet	44837-0005001-DataSheet.pdf	1822940	no	8
			8aed3cbad9ae0ed59b6d32bf030eb80cee3104ae		
Warnings:					
Information:					
2		44837-0005001-Spec.pdf	150653	yes	27
			7011617453ef9ed7d0f3998a295550402cca0f95		
	Multipart Description/PDF files in .zip description				
	Document Description		Start	End	
	Specification		1	20	
	Claims		21	26	
	Abstract		27	27	
Warnings:					
Information:					
3	Transmittal of New Application	44837-0005001-PaP.pdf	114957	no	2
			73cd669f6c663d547a95478dec28d8a98a9188c2		
Warnings:					
Information:					
4	Drawings-only black and white line drawings	44837-0005001-Figs.pdf	203941	no	12
			3d3db8b806b8191836bee68c43313cbd50a1020f		
Warnings:					
Information:					
5	Nonpublication request from applicant	44837-0005001-Non-Publication.pdf	93822	no	1
			fb7182c96d53aeb81c525fd79a4bee6060f8d89f		

Warnings:					
Information:					
6	Fee Worksheet (SB06)	fee-info.pdf	39664	no	2
			a666734603370a7be4f69b3ec8eef67928b68b4b		
Warnings:					
Information:					
Total Files Size (in bytes):			2425977		
This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503. <u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application. <u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course. <u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.					

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	44837-0005001
		Application Number	
Title of Invention	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

Secrecy Order 37 CFR 5.2:

☐	Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)
--------------------------	---

Inventor Information:

Inventor	1				Remove
Legal Name					
Prefix	Given Name	Middle Name	Family Name	Suffix	
	Timothy	James	O'Shea		
Residence Information (Select One) ☒ US Residency ☐ Non US Residency ☐ Active US Military Service					
City	Arlington	State/Province	VA	Country of Residence	US

Mailing Address of Inventor:

Address 1	1021 North Garfield Street, Apt. 646				
Address 2					
City	Arlington	State/Province	VA		
Postal Code	22201	Country	US		

Inventor	2				Remove
Legal Name					
Prefix	Given Name	Middle Name	Family Name	Suffix	
	James		Shea		
Residence Information (Select One) ☒ US Residency ☐ Non US Residency ☐ Active US Military Service					
City	Arlington	State/Province	VA	Country of Residence	US

Mailing Address of Inventor:

Address 1	2043 Wilson Blvd., #17039				
Address 2					
City	Arlington	State/Province	VA		
Postal Code	22216	Country	US		

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button.

Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below.
For further information see 37 CFR 1.33(a).

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	44837-0005001
		Application Number	
Title of Invention	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM		

☐ An Address is being provided for the correspondence information of this application.

Customer Number	26171		
Email Address		Add Email	Remove Email

Application Information:

Title of the Invention	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM		
Attorney Docket Number	44837-0005001	Small Entity Status Claimed	☒
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	12	Suggested Figure for Publication (if any)	

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☒ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	☒ Customer Number	☐ US Patent Practitioner	☐ Limited Recognition (37 CFR 11.9)
Customer Number	26171		

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	44837-0005001
		Application Number	
Title of Invention	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.

When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status	Pending	Remove	
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	Claims benefit of provisional	62/486200	2017-04-17
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the Add button.			Add

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)ⁱ the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

			Remove
Application Number	Country ⁱ	Filing Date (YYYY-MM-DD)	Access Code ⁱ (if applicable)
Additional Foreign Priority Data may be generated within this form by selecting the Add button.			Add

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013. NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	44837-0005001
		Application Number	
Title of Invention	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM		

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	44837-0005001
		Application Number	
Title of Invention	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM		

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Assignee	Legal Representative under 35 U.S.C. 117	Joint Inventor
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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	44837-0005001
		Application Number	
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First Name	Stephanie D.	Last Name	Grosvenor	Registration Number
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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	44837-0005001
		Application Number	
Title of Invention	MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM		

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MACHINE LEARNING-BASED NONLINEAR PRE-DISTORTION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. provisional application no. 62/486,200, filed on April 17, 2017. The disclosure of the prior application is considered part of and is incorporated by reference in the disclosure of this application.

TECHNICAL FIELD

This specification relates to integrating nonlinear pre-distortion machine learning into radio communication systems to correct for radio signal distortion and interference.

BACKGROUND

Radio communication systems include transmitting radio signal processing systems and receiving systems as well as various sources, e.g., amplifiers, which distort or interfere with radio signals being communicated by the transmitters to the receivers. This distortion or interference can alter, modify, or disrupt signal waveforms between transmission and reception.

A machine learning model receives input and generates output based on its received input and on values of model parameters.

Neural networks are machine learning models that employ one or more layers of nonlinear units to predict an output for a received input. Some neural networks include one or more hidden layers in addition to an output layer. The output of each hidden layer is used as input to other layers in the network, e.g., the next hidden layer or the output layer. Each layer of the network generates an output from a received input in accordance with current values of a respective set of parameters. These neural networks can be trained to generate predicted output.

SUMMARY

This specification describes technologies for machine learning systems in general, and specifically to systems and methods for pre-distorting radio signals of radio communication systems using a nonlinear pre-distortion machine learning model.

In general, one innovative aspect of the subject matter described in this specification can be embodied in methods that include the actions of correcting distortion or interference of radio signals. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods. For a system of one or more processors to be configured to perform particular operations or actions means that the system has installed on it software, firmware, hardware, or a combination of them that in operation cause the system to perform the operations or actions. For one or more computer programs to be configured to perform particular operations or actions means that the one or more programs include instructions that, when executed by data processing apparatus, cause the apparatus to perform the operations or actions.

The foregoing and other embodiments can each optionally include one or more of the following features, alone or in combination. In particular, one embodiment includes all the following features in combination.

A transmit radio signal that corresponds to an output of a transmitting radio signal processing system is obtained. A pre-distorted radio signal is generated by processing the transmit radio signal using a nonlinear pre-distortion machine learning model. The nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to correct radio signal distortion and/or interference. A transmit output radio signal is obtained by processing the pre-distorted radio signal through the transmitting radio signal processing system. The transmit output radio signal is then transmitted to one or more radio receivers.

In some implementations, the model parameters are updated with values for a particular deployment scenario for a radio communication system upon initial deployment of the nonlinear pre-distortion machine learning model into the radio communication system.

In some implementations, a signal may be received from one or more radio receivers corresponding to the transmit output radio signal that was transmitted to the one or more radio receivers.

In some implementations, the model parameters are updated based on a distance metric computed between the transmit radio signal corresponding to output of a transmitting radio signal processing system and the received signal of the one or more radio receivers.

The model parameters can additionally or alternatively be updated through a management process to minimize a distance metric or depending on at least one environment condition within the radio communication system.

An environment condition may be: temperature, humidity, antenna impedance, power levels, or candidate transmit signal type.

The particular deployment scenarios may be one or: sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in an inline mode; sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in a fault-tolerant subtractive mode; sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in an inline mode; sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in a fault-tolerant subtractive mode; sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates off a hardware chip and provides pre-distorted signals on the hardware chip or off the hardware chip; sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates on-chip and provides pre-distorted signals on a hardware chip; sending a radio transmission to a backhaul or satellite relay radio system and using feedback from one or more amplifiers to determine model parameters of the nonlinear pre-distortion machine learning model; or sending radio transmission to a system that includes interference cancellation.

Correcting distortion of radio signals may include correcting interference of radio signals.

In some implementations, in order to train a nonlinear pre-distortion model to correct distortion of radio signals, a candidate transmit radio signal corresponding to output of a transmitting radio signal processing system may be obtained. The candidate transmit radio signal is processed using a nonlinear pre-distortion machine learning model that executes using a set of model parameters to generate a pre-distorted candidate transmit radio signal. The nonlinear pre-distortion machine learning model includes at least one nonlinear function

to correct one or more of radio signal distortion or interference. A received radio signal corresponding to input of a radio receiver is obtained by processing the pre-distorted candidate transmit radio signal using one or more sources of distortion or interference. A distance metric is computed between the candidate transmit radio signal and the received radio signal. Updated values for the set of model parameters of the nonlinear pre-distortion machine learning model are determined that minimize the distance metric computed between the candidate transmit radio signal and the received radio signal to correct for one or more sources of alteration of the candidate transmit radio signal in the transmitting radio signal processing system. The values of the set of model parameters of the nonlinear pre-distortion machine learning model are updated in order to train the nonlinear pre-distortion machine learning model.

The model parameters are initially either randomly chosen or are seeded from a random distribution. The model parameters can be optimized through a model optimization process to minimize radio signal distortion or interference.

In some implementations, the distance metric is selected from one of: a mean squared error, absolute error, or computed between the candidate transmit radio signal and the received radio signal to form a quantitative measurement of an error value. A type of model chosen for the nonlinear pre-distortion machine learning model may be updated in addition to updating the values of the set of model parameters of the nonlinear pre-distortion machine learning model using the model optimization process.

In some implementations, the initial values for the model parameters are computed using a distance metric in a pre-deployment environment for a specific device or type of device. The candidate transmit radio signal may meet a desired use case for a particular deployment scenario.

The distance metric between the candidate transmit radio signal and the received radio signal may minimize cross-entropy towards a non-distorted target of a secondary trained classifier network trained to classify loss between a distorted and a non-distorted signal. The received radio signal may be received after a wireless transmission from an antenna, or after a relay system receivers, amplifiers, and retransmits the pre-distorted candidate transmit radio signal.

The nonlinear pre-distortion machine learning model may be a deep neural network, a convolutional neural network, a convolutional neural network, a recurrent neural network, or a combination of different types of neural networks.

Determining updated values for the model parameters may include using Stochastic Gradient Descent style optimizers that iteratively minimize the distance metric based on an exact or approximate gradient of the distance metric with regard to the model parameters.

Another implementation comprising one or more processors and one or more storage devices storing instructions that are operable, when executed the on one or more processors, to cause the one or more processors to perform any of the above implementations.

Still another implementation may be one or more non-transitory computer-readable storage mediums comprising instructions stored thereon that are executable by a processing device and upon such execution cause the processing device to perform any of the above implementations.

The subject matter described in this specification can be implemented in particular embodiments so as to realize one or more of the following advantages.

In conventional radio communication systems, in order to obtain acceptable linear modulation performance or minimally distorted or interference-free output, amplifiers are carefully designed for linearity and operated at non-maximal output powers (e.g., before severe compression), limiting the amplifiers efficiency for fidelity and leading to expensive design and parts. Operating amplifiers at non-maximal output in more linear regions can significantly increase cost and power consumption.

A radio communication system with an integrated nonlinear pre-distortion machine learning model as disclosed herein can minimize interference and distortion while operating amplifiers at maximal or near maximal output power levels. The system has a greater capacity for removing interference and correcting distortion than traditional systems and achieves greater linearity. Further, the system can accurately correct for distortion and interference due to non-linear effects within the system. The system can also model and suppress interference occurring over large time delays and large bandwidths of input signals. The system is also able to be realized in a computationally efficient form requiring smaller data types and more concurrent operations at lower clock speeds which lead to reduced

power consumption and computational requirements when compared with existing digital pre-distortion methods (e.g. polynomial models or otherwise).

The details of one or more embodiments of the subject matter of this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages of the subject matter will become apparent from the description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an overall system diagram that shows an example radio communication system with an integrated nonlinear pre-distortion system operation for correcting radio signal distortions and interferences.

FIG. 2 illustrates an example flow diagram of an example process for correcting radio signal distortions and interferences within a radio communication system.

FIG. 3 illustrates the functionality of an example nonlinear pre-distortion machine learning model.

FIG. 4 illustrates a flow diagram of an example process for training a nonlinear pre-distortion machine learning model to determine pre-distorted radio signals that correct distortions and interferences of a radio communication system.

FIG. 5A illustrates an example configuration of a nonlinear pre-distortion system for model training.

FIG. 5B illustrates an example configuration of a nonlinear pre-distortion system for online model tuning.

FIG. 6A illustrates an example configuration for in-line mode within a tower-mounted amplifier.

FIG. 6B illustrates an example configuration for fault-tolerant subtractive mode within the tower-mounted amplifier.

FIG. 7A illustrates an example configuration for in-line mode within a remote radio unit.

FIG. 7B illustrates an example configuration for fault-tolerant subtractive mode within the remote radio unit.

FIG. 8 illustrates an example configuration for a satellite relay system.

FIG. 9 illustrates an example configuration for a system that includes interference cancellation.

Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

This specification generally describes a radio communication system, integrated with a nonlinear pre-distortion machine learning model to correct for radio signal distortions and interferences.

For example, a machine learning model may be trained to predict a pre-distorted radio signal for a given transmit radio signal that minimizes a distance metric between the transmit radio signal that is transmitted from a transmit radio processing system and a received radio signal that is received by a receiver.

FIG. 1 illustrates an example radio communication system 100 with an integrated nonlinear pre-distortion system for correcting radio signal distortions and interferences. Within the radio communication system 100, a transmitting radio signal processing system 101 transmits radio signals to a receiver 109. In the transmission process, one or more components, e.g., an amplifier 108, of the radio communication system 100 may distort or interfere with the radio signals to be transmitted to a receiver 109. The radio communication system 100 may have multiple sources of distortion and/or interference.

For example, the radio communication system 100 may include at least one radio frequency (RF) power amplifier 106 that amplifies radio signals but also distorts signal waveforms. As illustrated, the amplifier 106 is separate from the transmitting radio signal processing system 101. However, in some implementations the amplifier can be tightly integrated (e.g., within a handset) or loosely coupled (e.g., a tower mounted amplifier) within the transmitting radio signal processing system 101.

Signal interference may occur when the radio communication system 100 experiences large time delays or transmits large bandwidths of data streams that include the radio signals. Other sources of distortion or interference include reflectors; bad connectors; imperfections in the digital to analog conversion process; unintended coupling, impedance mismatch or emissions for other electronics; unintended tones, intermodulation products or

sidelobes; responses from other analog electronic components such as filters, power supplies, matching networks, junctions, attenuators, and mixers. The radio communication system 100 uses a nonlinear pre-distortion system 103 to correct the radio signal distortion and interference prior to the radio signals being transmitted to the receiver 109.

As shown in FIG. 1, the nonlinear pre-distortion system 103 uses a nonlinear pre-distortion machine learning model 102 to determine pre-distorted radio signals that minimize a distance between the radio signals that the transmitting radio signal processing system 107 transmits and radio signals the receiver receives 108. The machine learning model 102 takes a transmit radio signal 104 as input and generates a pre-distorted signal 105 as output. The machine learning model 102 is described in more detail below with respect to FIG. 3.

The nonlinear pre-distortion system 103 of FIG. 1 includes both a non-linear pre-distortion machine learning model 102 and a machine learning model training process 113. The machine learning model training process 113 trains the machine learning model to minimize a distance between the transmitted radio signals and the received signals.

In some implementations, only the nonlinear pre-distortion machine learning model 102 is deployed within the radio communication system 100. In this implementation, the machine learning model 102 is trained on one or more of real and simulated data prior to deployment.

In other implementations, the nonlinear pre-distortion system 103 is deployed in the radio signal communication system in order for the nonlinear pre-distortion system 103 to perform online tuning and continue to train and update model parameters during real time execution. In this implementation, the machine learning model training process 113 receives the received signal 111, which includes both the pre-distortion and the distortion effects, from the receiver to determine real time online tuning and model parameter updates. This process can continue to compensate for changes in the response of a specific amplifier device over its lifetime and through changes in environmental conditions or signal loading conditions. The machine learning training process 113 is described in more detail below, with respect to FIG. 4.

FIG. 2 illustrates a flow diagram of an example process for correcting radio signal distortions and interferences within a radio communication system. The process 200 can be performed by a system of one or more computing devices, located in one or more locations,

and programmed appropriately in accordance with this specification. For example, the radio communication system 100 of FIG. 1, appropriately programmed, can perform process 200.

As illustrated in FIG. 2, to correct radio signal distortion and interference, the system obtains a transmit radio signal corresponding to output of a transmitting radio signal processing system 202. In some examples, the system may use a model execution controller to transmit the transmit radio signal, for example to control or track the state of the transmitting software or to control or track a mode of the pre-distortion model. Examples of mode may be GSM, LTE, HSPA, or different bandwidths of LTE (e.g., 5 MHz, 10 MHz, 20 MHz), or different numbers of aggregated LTE carriers 3x20 MHz. The state may include how loaded the system is, whether the system is completely filled with traffic, whether the system has idle or unoccupied resource blocks. The transmit radio signal is transmitted from the transmit radio signal system to the nonlinear pre-distortion machine learning model.

The system then generates a pre-distorted radio signal by processing the transmit radio signal using the nonlinear pre-distortion machine learning model 204.

Referring to FIG. 3, the nonlinear pre-distortion machine learning model 102 may be a neural network, e.g., a deep neural network, a convolutional neural network, a recurrent neural network, or a combination of any of these types of neural networks. Neural networks are machine learning models that employ one or more layers of neurons to generate an output, e.g., one or more classifications, for a received input. Deep neural networks include one or more hidden layers in addition to an output layer. The output of each hidden layer is used as input to other layers in the network, i.e., another next hidden layer or the output layer. Each layer of the neural network generates an output from a received input in accordance with current values of a respective set of parameters (weights 312) for the layer. These neural networks may be trained as a generative adversarial network, where multiple objectives such as generation (e.g. generating one signal from another signal) and classification (e.g. determining a distorted signal from a non-distorted signal) are jointly or iteratively optimized between two or more tightly coupled networks. These neural networks may also be trained using autoencoders, wherein a network may be trained to produce a reconstruction of a signal through an intermediate representation of the signal (e.g. a smaller or otherwise constrained latent version of the signal, which can be used to retain key structural components of the signal). Neural networks may also employ residual units, skip connections, or similar

whereby connections from one layer to another may find various paths throughout the network, providing representation capabilities beyond more traditional sequential neural network models which always feed from one layer to its direct successor. The neural network model may be selected from a plurality of possible model architectures (e.g. connections, layer sizes, hyper-parameter settings) based on an automated search process during the training phase in order to optimize performance.

As illustrated, the machine learning model 102 takes in one or more transmit radio signals 104 as input. The input signals 305 and input values to other layers are combined using multiplications with weight vectors 312 and accumulates/summations of these products along with bias vectors along with other operations such as batch normalization, dropout, exponentiation, or otherwise which operate on activations to produce . The weight vectors are multiplied with neuron layer inputs, while bias vectors are added with the products of these summations (e.g., $\text{out} = \text{activation}(\text{in}_0 * w_0 + \text{in}_1 * w_1 + b_0)$). The weight vectors of all the layers as well as other parameters including bias vectors are referred to as model parameters.

The results of the multiplications and accumulations 306 form outputs that are passed through nonlinear transform functions 308. The transformation functions can be one or more of linear, sigmoid, exponential, hyperbolic tangent, rectified linear (ReLU), leaky-ReLU, or one of many other potential forms of nonlinear activation function that works optimally to minimize a distance metric or loss function. The output signals 308 are combined to produce a pre-distorted radio signal 105 as model output. This output may be comprised of In-phase and Quadrature (I/Q) time domain samples which can be converted to a complex or real analog signal.

Referring back to FIG. 2, after generating a pre-distorted radio signal from the nonlinear pre-distortion machine learning model, the system obtains a transmit output radio signal by processing the pre-distorted radio signal through the transmitting radio signal processing system 206. For example, the transmitting radio signal processing system may appropriately tune, scale or modify the pre-distorted radio signal, or it may compute a difference signal between the pre-distorted signal and the input signal (e.g. for subtractive pre-distortion). The system converts the signal to an analog signal by a digital to analog converter. Once the signal has been converted, the generated signal may be considered a

transmit output radio signal that is ready to transmit, or in the case of a difference signal may be additively combined with the original signal using an analog signal summation device.

The system then transmits the transmit output signal to one or more radio receivers 208. The transmit output signal can be transmitted through a target hardware amplifier device that introduces distortions and/or interference into the signal. The transmit output signal may also be transmitted through an antenna. The signal is then usually converted back into a digital signal using an analog to digital converter to form a signal that can be processed within the digital processor of the remote receivers. This received signal includes both the pre-distortion and the distortion effects, which in ideal circumstances combine to form a highly linear and ideal signal over the air which accurately reflects the modulation basis of the transmitting system (e.g. an OFDM or SC-FDMA modulator which might be used in a cellular transceiver).

In order to provide pre-distorted signals, a system trains the nonlinear pre-distortion machine learning model to predict pre-distorted signals based on given input. Referring to FIG. 1, the machine learning training process 113 can train the machine learning model 102 in simulation or on real radio communication systems to predict pre-distorted signals that minimize a distance metric.

FIG. 4 illustrates a flow diagram of an example process 400 for training a nonlinear pre-distortion machine learning model to correct distortion and interference. The process 400 can be performed by a system of one or more computing devices, located in one or more locations and programmed appropriately in accordance with this specification. For example, the nonlinear pre-distortion system 103 of FIG. 1, appropriately programmed, can perform process 400.

To train the machine learning model, the system initializes values of a set of parameters for the machine learning model. The values can be initially randomly chosen or seeded from a random distribution. The model may have a fixed model architecture defining the node types and connections, which may be chosen from among a plurality of model architectures based on multiple training processes and comparison of distance metrics. The initial parameters may also be chosen for a specific device or type of devices in a pre-deployment environment or based on devices or types of devices expected in a deployment

environment in which the machine learning model will be deployed, in this case the parameters may be taken from another similar model.

The system obtains a candidate transmit radio signal corresponding to output of a transmitting radio signal processing system 402. A model execution controller can control the transmission of the candidate transmit waveforms that meet desired use cases of target amplifiers and waveforms for a deployment scenario for which the machine learning model is being trained. For example, the candidate transmit waveforms may reflect the radio signals that would be transmitted in a target deployed radio communication system, such as an LTE base station signal, a point-to-point microwave or mm-wave backhaul signal, in this way the training process can train on one or more modes of a representative set of protocols and transmission modes and conditions similar to those which will occurring in operation.

The system then processes the candidate transmit radio signal using the nonlinear pre-distortion machine learning model that executes using the set of model parameters to generate a pre-distorted candidate transmit radio signal 404.

The system obtains a received radio signal corresponding to input of a radio receiver by processing the pre-distorted candidate transmit radio signal using one or more sources of distortion or interference 406. Other sources of distortion or interference include reflectors; and bad connectors; imperfections in the digital to analog conversion process; unintended coupling, impedance mismatch or emissions for other electronics; unintended tones, intermodulation products or sidelobes; responses from other analog electronic components such as filters, power supplies, matching networks, junctions, attenuators, mixers, etc.

The system computes a distance metric between the candidate transmit radio signal and the received radio signal 408. The distance metric is selected from one of several options including: a mean squared error, an absolute error, or some other computation between the transmit radio signal and the received radio signal to form a quantitative measurement of the error vector. The distance metric between the candidate transmit radio signal and the received radio signal may be to minimize cross-entropy towards a non-distorted target of a secondary trained classifier network trained to classify loss between a distorted and a non-distorted signal (e.g. an adversarial network)

The system determines updated values for the set of model parameters of that minimize the distance metric computed between the candidate transmit radio signal and the received radio signal 410.

In some implementations, the system iterates over multiple candidate transmit radio signals that correspond to various potential deployment scenarios of the radio communication system to continually reduce the distance metric computed between the transmitted and received radio signals. The system may perform training using many sequential samples in a transmit waveform to encapsulate long-temporal distortion effects in addition to short-time distortion effects. For instance, the process of distorting memory effects within amplifier devices may operate on multiple timescales such as nano-second and micro-second scale effects, while a processing for cancellation of delayed artifacts of the primary signal may need to operate to remove effects a single sample away, or hundreds or more of samples away, depending on the rate of the sampling, the temporal scale of the distortions, and the pre-distortion model architecture.

In some implementations, the error value or loss value corresponding to the distance metric is used to guide model selection (e.g. by training and evaluating a plurality of possible model architectures and selecting those with lower distance metrics for further evaluation or usage).

FIG. 5A illustrates an example configuration of a nonlinear pre-distortion system for model training. In some implementations, the nonlinear pre-distortion system 500a is the same as the nonlinear pre-distortion system 103. The nonlinear pre-distortion machine learning model in configuration 500a provides a pre-distorted radio signal 503 to a modeled source of distortion or interference 504. The distortion or interference source produces a modeled received radio signal 505 that can be used by a distance computation process 508 to compute a distance metric between the candidate transmit radio signal 501 and the modeled received radio signal 505. The system then sends the computed distance metric to a model optimization process 510. This process determines updated parameters for the machine learning model that minimize the distance metric. The goal of the optimization process is to provide parameters that will allow the radio communication system to have the best performance, e.g., the least distorted signals. The system updates model values using Stochastic Gradient Descent-style optimizers, e.g. Adam, AdaGrad, or Nesterov Stochastic

Gradient Descent, to help iteratively minimize the distance metric based on an exact or approximate gradient of the distance metric with regard to the model parameters. In some implementations, the model optimization process selects optimal models to use as the nonlinear pre-distortion machine learning model 103 in addition to determining updated parameters for a model, for example by selecting models which achieve best model performance from a plurality of models through a search process.

FIG. 5B illustrates an example configuration of a nonlinear pre-distortion system for online model tuning. In some implementations, the nonlinear pre-distortion system 500a is the same as the nonlinear pre-distortion system 103. In Fig. 5B, the nonlinear pre-distortion machine learning model in configuration 500b is deployed in a real-time execution environment. A transmitting radio signal processing system 101 provides actual transmit signals 104 to the nonlinear pre-distortion machine learning model 103. The model provides pre-distorted signals 105 that the transmitting radio signal processing system 101 processes as described above to obtain a ready-to-transmit pre-distorted signal 107. In some implementations, an amplifier 106 amplifies the signal to generate a post-distorted signal 108 that is received by a receiver 109. In other implementations, the receiver 109 may amplify and retransmit the signal. In the online tuning configuration, the receiver 109 sends the received signal 111 to the nonlinear pre-distortion system in order for the system to compute the distance metric between the transmit signal 104 and the received signal 111. The model optimization process 510 then computes updated pre-distortion model parameters 109 for the nonlinear pre-distortion machine learning model 103 in order to minimize the distance metric. This processing continually updates the parameters during real time execution to tune the model.

In addition to training and model tuning, the nonlinear pre-distortion system can include a management process for managing model parameter updates. These updates can be based on a pre-deployment environment or a deployment environment within a radio communication system in which a nonlinear pre-distorted machine learning model is deployed. Environment conditions can include temperature, humidity, antenna impedance, power levels, or candidate transmit signal type.

The nonlinear pre-distortion system 103 can be deployed in several different deployment configurations. For example, the nonlinear pre-distortion system 103 can be

deployed within base stations, e.g., cellular, Wi-Fi, backhaul, or radio system. FIGs. 6A and 6B illustrate example configurations within tower-mounted amplifiers of a base station. FIG. 6A illustrates an example configuration for in-line mode within a tower-mounted amplifier, placing a nonlinear pre-distortion system 103 between an input 601 and an amplifier 603. FIG. 6B illustrates an example configuration for fault-tolerant subtractive mode within the tower-mounted amplifier, with the nonlinear pre-distortion system 103 configured between an RF splitter 606 and an analog subtract 607. FIGs. 7A and 7B illustrate example configurations within remote radio units of a base station. FIG. 7A illustrates a configuration for in-line mode within a remote radio unit, with the nonlinear pre-distortion system 103 configured between the input 701 and the amplifier 703. FIG. 7B illustrates an example configuration for fault-tolerant subtractive mode within the remote radio unit with the machine learning model 102 and the machine learning model training process 113 separated.

In one implementation, the nonlinear pre-distortion system 103 can be deployed inside a single chip of a radio frequency integrated circuit (RFIC) device, e.g., an AD9361 or a Qualcomm RTR chip and a baseband processor. In such deployments, the system 103 can reside on the radio system on a chip and/or the baseband processing system on a chip on a phone or other mobile device, e.g., laptop, tablet. The nonlinear pre-distortion model can exist either in the baseband processing system on a chip with off chip model parameter updates or in the radio system on a chip with off-chip model parameter updates (e.g. model parameter updates and tuning may occur at a slower rate, execute on a different processor, a remote location, or other configuration). In an alternative implementation, the nonlinear pre-distortion system 103 can be deployed completely within a single chip of a RFIC device.

The nonlinear pre-distortion system 103 can be deployed in a backhaul or satellite relay radio system. FIG. 8 illustrates an example configuration 800 for a satellite relay system 801. The satellite relay system 801 includes an amplifier 802 that distorts signals. The configuration 800 may also include an amplifier 805 for transmission. One or more amplifiers' distortion effects may be taken into consideration when updating the machine learning model using the machine learning model training process 113.

The nonlinear pre-distortion system 103 can additionally or alternatively be deployed in a system for interference cancellation. In this case, interference, for example from nearby emitters or sources of interference can be suppressed or removed from the received signal to

allow for improved radio system performance. One source of such interference is two co-located base stations operating on frequencies whereby harmonics of the transmitted signals when mixed together by non-linear junctions, such can occur in rusty metals, produce interfering signals in the receive band of one base station in a process known as Passive Intermodulation (PIM) distortion. FIG. 9 illustrates an example configuration 900 for a system that includes interference cancellation. This configuration uses an equivalent network which modifies a received radio signal 912 and passes it through a distortion/interference removal network 905 in order to remove artifacts resulting from an interference source which may be sensed at another antenna 911. To accomplish this the network uses a similar distance metric to minimize or remove any dependent signal content from the interference signal 911 present within the received signal 912. In a pre-distortion on transmit system, a sensor such as 912 may be used after radio transmission to compensate additionally for impairments and distortion to the signal which occurs after transmission from the base station.

Embodiments of the subject matter and the functional operations described in this specification can be implemented in digital electronic circuitry, in tangibly-embodied computer software or firmware, in computer hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Embodiments of the subject matter described in this specification can be implemented as one or more computer programs, i.e., one or more modules of computer program instructions encoded on a tangible non-transitory storage medium for execution by, or to control the operation of, data processing apparatus. The computer storage medium can be a machine-readable storage device, a machine-readable storage substrate, a random or serial access memory device, or a combination of one or more of them. Alternatively or in addition, the program instructions can be encoded on an artificially-generated propagated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal, which is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus.

The term “data processing apparatus” refers to data processing hardware and encompasses all kinds of apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers.

The apparatus can also be, or further include, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application-specific integrated circuit). The apparatus can optionally include, in addition to hardware, code that creates an execution environment for computer programs, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of one or more of them.

A computer program, which may also be referred to or described as a program, software, a software application, an app, a module, a software module, a script, or code, can be written in any form of programming language, including compiled or interpreted languages, or declarative or procedural languages; and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A program may, but need not, correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data, e.g., one or more scripts stored in a markup language document, in a single file dedicated to the program in question, or in multiple coordinated files, e.g., files that store one or more modules, sub-programs, or portions of code. A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a data communication network.

The processes and logic flows described in this specification can be performed by one or more programmable computers executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by special purpose logic circuitry, e.g., an FPGA or an ASIC, or by a combination of special purpose logic circuitry and one or more programmed computers.

Computers suitable for the execution of a computer program can be based on general or special purpose microprocessors or both, or any other kind of central processing unit. Generally, a central processing unit will receive instructions and data from a read-only memory or a random access memory or both. The essential elements of a computer are a central processing unit for performing or executing instructions and one or more memory devices for storing instructions and data. The central processing unit and the memory can be supplemented by, or incorporated in, special purpose logic circuitry. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both,

one or more mass storage devices for storing data, e.g., magnetic, magneto-optical disks, or optical disks. However, a computer need not have such devices. Moreover, a computer can be embedded in another device, e.g., a mobile telephone, a personal digital assistant (PDA), a mobile audio or video player, a game console, a Global Positioning System (GPS) receiver, or a portable storage device, e.g., a universal serial bus (USB) flash drive, to name just a few.

Computer-readable media suitable for storing computer program instructions and data include all forms of non-volatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g., internal hard disks or removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks.

To provide for interaction with a user, embodiments of the subject matter described in this specification can be implemented on a computer having a display device, e.g., a CRT (cathode ray tube) or LCD (liquid crystal display) monitor, for displaying information to the user and a keyboard and a pointing device, e.g., a mouse or a trackball, by which the user can provide input to the computer. Other kinds of devices can be used to provide for interaction with a user as well; for example, feedback provided to the user can be any form of sensory feedback, e.g., visual feedback, auditory feedback, or tactile feedback; and input from the user can be received in any form, including acoustic, speech, or tactile input. In addition, a computer can interact with a user by sending documents to and receiving documents from a device that is used by the user; for example, by sending web pages to a web browser on a user's device in response to requests received from the web browser. Also, a computer can interact with a user by sending text messages or other forms of message to a personal device, e.g., a smartphone, running a messaging application, and receiving responsive messages from the user in return.

Embodiments of the subject matter described in this specification can be implemented in a computing system that includes a back-end component, e.g., as a data server, or that includes a middleware component, e.g., an application server, or that includes a front-end component, e.g., a client computer having a graphical user interface, a web browser, or an app through which a user can interact with an implementation of the subject matter described in this specification, or any combination of one or more such back-end, middleware, or front-end components. The components of the system can be interconnected by any form or

medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network (LAN) and a wide area network (WAN), e.g., the Internet.

The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other. In some embodiments, a server transmits data, e.g., an HTML page, to a user device, e.g., for purposes of displaying data to and receiving user input from a user interacting with the device, which acts as a client. Data generated at the user device, e.g., a result of the user interaction, can be received at the server from the device.

While this specification contains many specific implementation details, these should not be construed as limitations on the scope of any invention or on the scope of what may be claimed, but rather as descriptions of features that may be specific to particular embodiments of particular inventions. Certain features that are described in this specification in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially be claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system modules and components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

Particular embodiments of the subject matter have been described. Other embodiments are within the scope of the following claims. For example, the actions recited in the claims can be performed in a different order and still achieve desirable results. As one example, the processes depicted in the accompanying figures do not necessarily require the particular order shown, or sequential order, to achieve desirable results. In some cases, multitasking and parallel processing may be advantageous.

What is claimed is:

CLAIMS

1. A method for correcting distortion of radio signals, the method comprising:
obtaining a transmit radio signal corresponding to an output of a transmitting radio signal processing system;
generating a pre-distorted radio signal by processing the transmit radio signal using a nonlinear pre-distortion machine learning model, wherein the nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to correct radio signal distortion;
obtaining a transmit output radio signal by processing the pre-distorted radio signal through the transmitting radio signal processing system; and
transmitting the transmit output radio signal to one or more radio receivers.
2. The method of claim 1, wherein the model parameters are updated with values for a particular deployment scenario for a radio communication system upon initial deployment of the nonlinear pre-distortion machine learning model into the radio communication system.
3. The method of claim 1, further comprising:
receiving a received signal from one or more radio receivers corresponding to the transmit output radio signal that was transmitted to the one or more radio receivers.
4. The method of claim 3, wherein the model parameters are updated based on a distance metric computed between the transmit radio signal corresponding to output of a transmitting radio signal processing system and the received signal of the one or more radio receivers.
5. The method of claim 1, wherein the model parameters are updated through a management process to minimize a distance metric.
6. The method of claim 2, wherein the model parameters are updated depending on at least one environment condition within the radio communication system.
7. The method of claim 6, wherein the environment condition is one of: temperature, humidity, antenna impedance, power levels, or candidate transmit signal type.

8. The method of claim 2, wherein the particular deployment scenario comprises one of:
 - sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in an inline mode;
 - sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in a fault-tolerant subtractive mode;
 - sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in an inline mode;
 - sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in a fault-tolerant subtractive mode;
 - sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates off a hardware chip and provides pre-distorted signals on the hardware chip or off the hardware chip;
 - sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates on-chip and provides pre-distorted signals on a hardware chip;
 - sending a radio transmission to a backhaul or satellite relay radio system and using feedback from one or more amplifiers to determine model parameters of the nonlinear pre-distortion machine learning model; or
 - sending radio transmission to a system that includes interference cancellation.
9. The method of claim 1, wherein correcting distortion of radio signals includes correcting interference of radio signals.

10. A method for training a nonlinear pre-distortion model to correct distortion of radio signals, the method comprising:

obtaining a candidate transmit radio signal corresponding to output of a transmitting radio signal processing system;

processing the candidate transmit radio signal using a nonlinear pre-distortion machine learning model that executes using a set of model parameters to generate a pre-distorted candidate transmit radio signal, wherein the nonlinear pre-distortion machine learning model includes at least one nonlinear function to correct one or more of radio signal distortion or interference;

obtaining a received radio signal corresponding to input of a radio receiver by processing the pre-distorted candidate transmit radio signal using one or more sources of distortion or interference;

computing a distance metric between the candidate transmit radio signal and the received radio signal;

determining updated values for the set of model parameters of the nonlinear pre-distortion machine learning model that minimize the distance metric computed between the candidate transmit radio signal and the received radio signal to correct for one or more sources of alteration of the candidate transmit radio signal in the transmitting radio signal processing system; and

updating the values of the set of model parameters of the nonlinear pre-distortion machine learning model in order to train the nonlinear pre-distortion machine learning model.

11. The method of claim 10, wherein the model parameters are initially either randomly chosen or are seeded from a random distribution.

12. The method of claim 10, wherein the model parameters are optimized through a model optimization process to minimize radio signal distortion or interference.

13. The method of claim 10, wherein the distance metric is selected from one of: a mean squared error, absolute error, or computed between the candidate transmit radio signal and the received radio signal to form a quantitative measurement of an error value.

14. The method of claim 12, further comprising:

updating a type of model chosen for the nonlinear pre-distortion machine learning model in addition to updating the values of the set of model parameters of the nonlinear pre-distortion machine learning model using the model optimization process.

15. The method of claim 10, wherein initial values for the model parameters are computed using a distance metric in a pre-deployment environment for a specific device or type of device.

16. The method of claim 10 wherein the candidate transmit radio signal meets a desired use case for a particular deployment scenario.

17. The method of claim 16, wherein the particular deployment scenario comprises one of:

sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in an inline mode;

sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a tower mounted amplifier in a fault-tolerant subtractive mode;

sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in an inline mode;

sending a radio transmission from a cellular base station that includes the nonlinear pre-distortion machine learning model inside a remote radio unit in a fault-tolerant subtractive mode;

sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates off a hardware chip and provides pre-distorted signals on the hardware chip or off the hardware chip;

sending a radio transmission to a mobile handheld device that includes the nonlinear pre-distortion machine learning model, which obtains model parameter updates on-chip and provides pre-distorted signals on a hardware chip;

sending a radio transmission to a backhaul or satellite relay radio system and using feedback from one or more amplifiers to determine model parameters of the nonlinear pre-distortion machine learning model; or

sending radio transmission to a system that includes interference cancellation.

18. The method of claim 10, wherein the distance metric between the candidate transmit radio signal and the received radio signal minimizes cross-entropy towards a non-distorted target of a secondary trained classifier network trained to classify loss between a distorted and a non-distorted signal.

19. The method of claim 10, wherein the received radio signal is received after a wireless transmission from an antenna, or after a relay system receives, amplifies and retransmits the pre-distorted candidate transmit radio signal.

20. The method of claim 10, wherein the nonlinear pre-distortion machine learning model is one of a deep neural network, a convolutional neural network, a recurrent neural network, or a combination of different types of neural networks.

21. The method of claim 10, wherein determining updated values for the model parameters includes using Stochastic Gradient Descent style optimizers that iteratively minimize the distance metric based on an exact or approximate gradient of the distance metric with regard to the model parameters.

22. The method of claim 10, wherein correcting distortion of radio signals includes correcting interference of radio signals.

23. A system comprising:

one or more processors; and

one or more storage devices storing instructions that are operable, when executed on the one or more processors, to cause the one or more processors to:

obtain a transmit radio signal corresponding to an output of a transmitting radio signal processing system;

generate a pre-distorted radio signal by processing the transmit radio signal using a nonlinear pre-distortion machine learning model, wherein the nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to correct radio signal distortion;

obtain a transmit output radio signal by processing the pre-distorted radio signal through the transmitting radio signal processing system; and

transmit the transmit output radio signal to one or more radio receivers.

24. One or more non-transitory computer-readable storage mediums comprising instructions stored thereon that are executable by a processing device and upon such execution cause the processing device to:

obtain a transmit radio signal corresponding to an output of a transmitting radio signal processing system;

generate a pre-distorted radio signal by processing the transmit radio signal using a nonlinear pre-distortion machine learning model, wherein the nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to correct at least one of radio signal distortion or interference;

obtain a transmit output radio signal by processing the pre-distorted radio signal through the transmitting radio signal processing system; and

transmit the transmit output radio signal to one or more radio receivers.

ABSTRACT

Methods, systems, and apparatus, including computer programs encoded on computer storage media, for correcting distortion of radio signals. A transmit radio signal corresponding to an output of a transmitting radio signal processing system is obtained. A pre-distorted radio signal is then generated by processing the transmit radio signal using a nonlinear pre-distortion machine learning model. The nonlinear pre-distortion machine learning model includes model parameters and at least one nonlinear function to correct radio signal distortion or interference. A transmit output radio signal is obtained by processing the pre-distorted radio signal through the transmitting radio signal processing system. The transmit output radio signal is then transmitted to one or more radio receivers.

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