Dynamic Range Improvements in Radar Systems using Transmitter Linearisation

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Abstract

The extension of existing Radar system dynamic range is integral to the EMRC DTC requirement for current sensors to see deeper into clutter (i.e., see small targets in the presence of large clutter levels e.g. urban clutter). The rationale behind this requirement being that this additional capability greatly enhances the utility of military& commercial systems. Therefore, the new Radar dynamic range enhancement methods presented in this paper have direct relevance to military and telecommunications applications, thereby greatly improving technology exploitation and business opportunities within the currently identified market segments.

Keywords: RADAR, Linearisation, Dynamic, Range, Systems, Transmitter

Introduction

The extension of existing Radar system dynamic range is integral to the EMRC DTC requirement for current sensors to see deeper into clutter (i.e., see small targets in the presence of large clutter levels e.g. urban clutter).

One method of increasing the dynamic range of a RADAR system is to increase the illumination on the target. Increasing the power output, either by increasing the power from the transmitter or by increasing the pulse length, can increase the illumination. In a Phased Array Radar (PAR) system increasing the power can be at the expense of higher thermal dissipation and increased pulse length can lead to the insertion phase and gain of a module changing during the pulse. This can lead to the array pattern either moving pointing angle or getting broader, neither of which are desired.

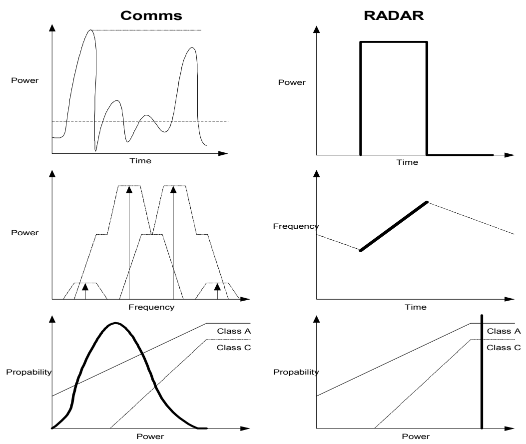
The method proposed for increasing the RF power, without increasing the thermal load, is to use Class C amplifiers, which are inherently more efficient. However, Class C amplifiers produce harmonics and have a gain dependant on signal strength. In order to overcome these limitations we have successfully researched novel methods or types of amplitude and phase preservation techniques for Class C amplifiers, when used within Radar systems. These new signal preservation methods provide Class C Radar amplifiers which achieve optimum performance in terms of power efficiency and phase & amplitude response, thereby leading to enhanced dynamic range performance.

In this paper we are basing our work on the requirements of the MESAR class of Active Phased Array RADAR's. Hence we assume there is a beamforming distribution network and an array of individual power amplifier. We are also assuming that the power amplifiers are working in saturation and there is no AM component of the RADAR waveform. If an AM component is proposed for the RADAR signal then some of the linearisation techniques rejected in the following discussions should be reconsidered.

Nature of Non Linearity

In communication systems it is common to use signals with AM modulation component, or to transmit multiple channels (frequencies) simultaneously through the transmitter chain. In Radar systems there is generally a requirement on the amount of power in adjacent channel. The signal Peak to Mean Power Ratio is an important parameter in Radar transmitter design.

The signals considered in communications and RADAR are different and this affects the design of the amplifier and the linearisation techniques that need to be considered.



Signal Characteristics

The above figure shows the signal characteristics for a dual channel type basestation and for a RADAR. The main difference being that the communication channel signal is time varying and has peak powers much greater than the mean power. In the RADAR system the power, during the pulse, is constant. The frequency may be chirped, but only one frequency is used at a time, so we don't get the amplitude beats seen in the communication system. Finally the compressed gain plots for the amplifiers are shown over the two signals. The RADAR amplifier is run in saturation, the communication amplifier is backed off to allow most of the peaks to be amplified with out clipping. The clipping can lead to data errors.

Linearisation Techniques

There are many methods of communications system linearisation, the exact choice depends on the signal peak to mean, the bandwidth and the required linearity improvement. Sometimes techniques are combined to achieve the requirements. More detailed explanations are given in Kenington [1]

Consideration has been given to modifying the linearisation techniques, not to replicate the gain variation in the input signal, but to compensate for any gain (and phase) variation added by the amplifiers.

Back off the Amplifier

The easiest linearisation technique is to back off the amplifier so that it is working almost small signal. There is often a cost and efficiency penalty. However it should also be noted that in high peak to mean systems the amplifier has to be specified to amplify most of the peaks, other wise severe clipping will take place. This can lead to a 100W amplifier specified for 10W mean power channels.

Delay and Time Constants

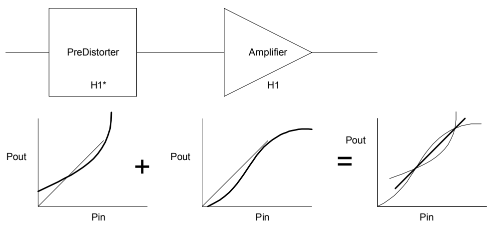
In this paper only simplified version of the amplifier systems have been shown. In every case the real system would be more complicated. In a real design the drift of the performance of the amplifier and other components over the life of the system would have to be considered and compensated for. In the control of the compensation the time constants of the loops and the requirement of the bandwidth, of both carrier and the data signals, will need to be considered. Also the delays introduced in the various paths would need to be considered as these affect both the feedforward and feedback systems. In general the choice of system depends on the requirements of the communication system and the link design.

Pre and Post Distortion

The first class of linearisation techniques considered are where the distortion introduced in the amplifier is corrected by using pre or post distortion the signal.

Pre Distortion

This is a commonly used technique in which the signal is first distorted, such that the distortion in the amplifier is cancelled. Commonly the gain compression characteristics of the amplifier are preceded by a gain expansion function. The resultant characteristic would have a linear gain expression.

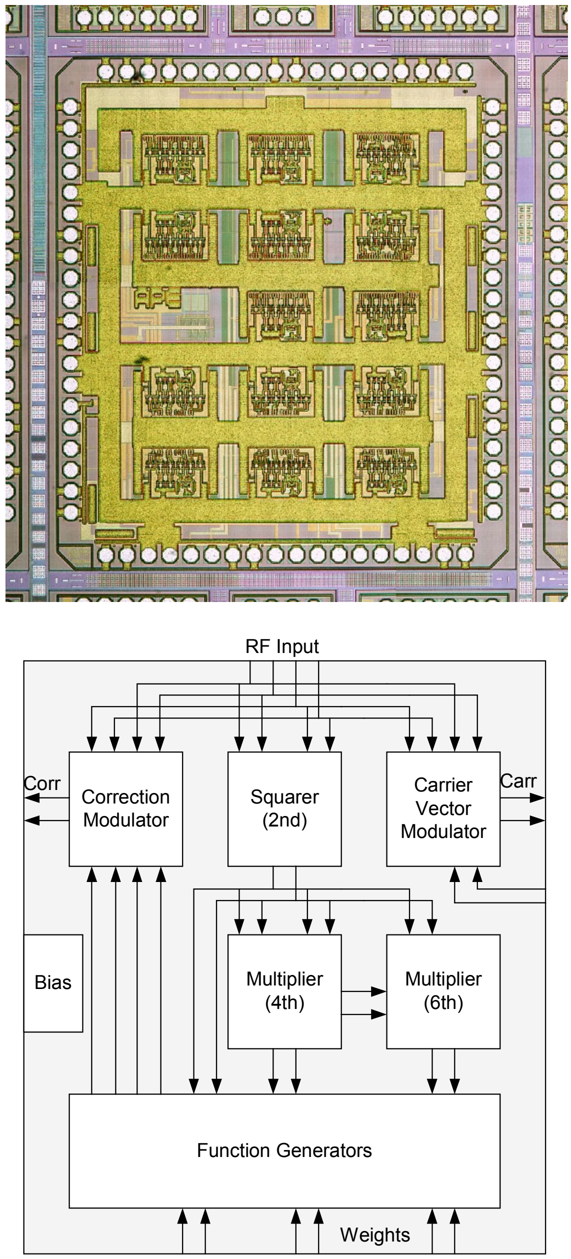


Pre Distortion

The phase can also be considered. The predistorter can be made with a diode, or by generating a compression curve with a suitable amplifier and using this in an analogue computer type circuit. More complex functions can be created by using harmonic generation circuits and by suitable addition and subtraction, or by generating the Predistortion in the baseband, even in the digital bit stream.

In the RADAR domain the input signal is not time variant, so most distorters would not be effective. The error introduced by the amplifier is not dependant on the input signal amplitude, but on the heating effects. A system could be considered where a pre distorter used the heating effect to produce an inverse response, but the limiting effects of the saturated amplifier would nullify the effect. Amplitude pre distortion is not recommended for RADAR, but a controlled phase only system could be considered and is discussed later

Adaptive Polynomial Equalisation



APE Chip Photograph and Block Diagram

Recently RMRL have produced an Adaptive Polynomial Equaliser IC which uses weighted products of the envelopes of the input signal to drive a vector modulator. This signal can then be used as a predistorter, or used to drive the error signal in a feedforward type loop. The chip works by multiplying the input signal and using the resultant modulated waveforms, but these do not exist in our RADAR. The IC was designed at RMRL and processed on the IBM SiGe HP5 process.

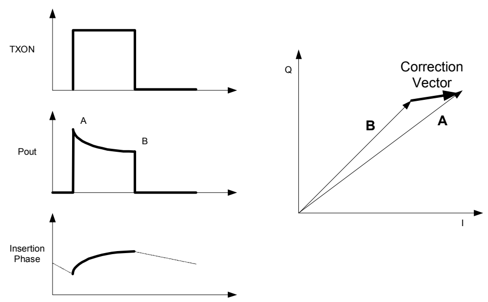
Harmonic Injection

Harmonic Injection is similar to Predistortion in that a harmonic of the input signal is also added to the signal. This harmonic is phased such that the resultant output harmonics are cancelled. The controlling of this phasing over all conditions has meant that this technique is not used so much in practice.

The technique has also been proposed for harmonic cancellation, but again use in real systems has been limited. This system was considered for a Class C Amplifier Harmonic reduction, but the harmonic introduced in a class C amplifier are part of the switching action, which is fundamental to its operation. If we cancel the harmonics before the amplifier, the input signal will have been re-biased to class A.

Post Distortion and Signal Addition

Although Predistortion is commonly used in linearised communication transmitters, as it can be done at lower powers and hence there is not a great penalty on the cost and efficiency of the system. Post distortion is done at the output and is not so common. Post distortion could be used for harmonic cancellation or to increase the signal level after the reduction of power in a long pulse.

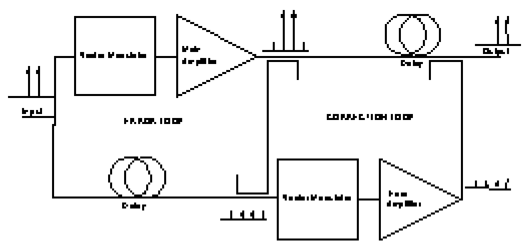


Required correction for a long pulse.

The challenge now becomes to find this RF power and to make sure it has the right control systems. To some extent a feedforward system is a post distortion system and this is considered in the next section.

Feed Forward

This is very common system in linearised communication amplifier transmitters. A main amplifier is placed in two loops and a second amplifier included, adding a post distortion cancellation signal to the system. The main advantage is that once the loops are adjusted to compensate for the delays and gain in the various paths, the variable elements are not used to modify the signal in real time. The error and correction loops both then work automatically. The time constants to control the loop compensators can be very long, and RMRL has used adaptive techniques to control the vector modulators in a trial system.

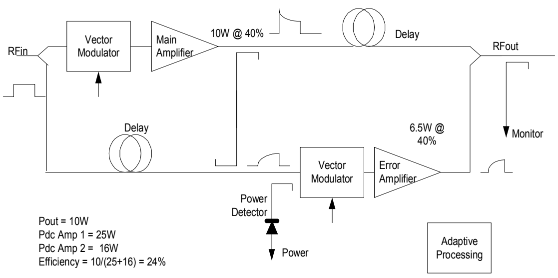


Communication Feedforward Amplifier Schematic

Feed Forward – Narrow Band

When designing a feedforward amplifier two critical decisions have to be made. The first is the choice of main amplifier. This then gives the expected distortion that needs to be corrected. The second choice is then the output coupler, as this then helps specify the error amplifier. In a communication system, with an intermodulation product of about -30 dBc, with a 10 dB coupler the error signal required is now 20 dB down on main amplifier output.

If we were to consider using a feedforward type system to correct for the pulse drop of 1dB, or 33% we would need a combiner, not a coupler, or the error amplifier has to generate more power than the main amplifier. This would have a major efficiency penalty.

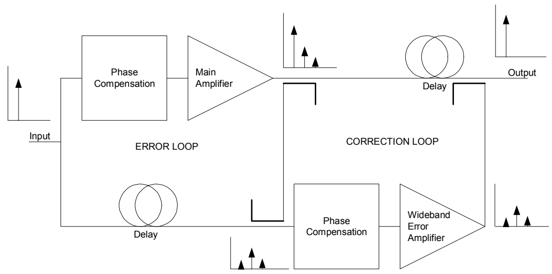


RADAR Narrow Band Feedforward system.

If we look at an example with a 10W amplifier at say 40% efficiency, if we have a helper amplifier at 2 dB down, then we will use 16W of dc power in the helper amplifier. This would mean the efficiency of the two amplifier combined is now less than 25%. It could be arranged that the helper amplifier is class C so does not take power at the start of the pulse, but we would be adding a lot of complexity to the basic amplifier just to correct the pulse droop. This topology is not recommended.

Feed Forward – Ultra Wideband

In this scenario the harmonics generated by the main amplifier are sampled and then the input signal removed from the sampled signal. The harmonics then need to be amplifier by the error amplifier and then added back in anti phase into the main signal path. This means that the error amplifier would have to be wide band or consist of a family of amplifiers, one for each harmonic to be cancelled. The frequency agility of modern RADAR's also makes the bandwidth of the error amplifier large.



Wideband feedforward.

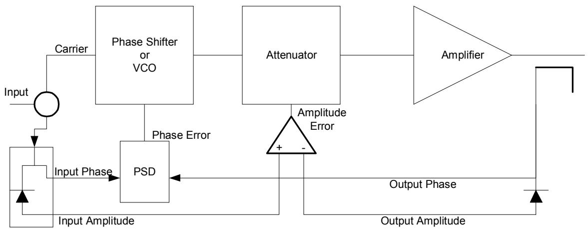
If we had a -30 dBc harmonic we wished to cancel and 10dB coupler, the error amplifier harmonic signal would be -20dBc down on the main channel power level. Hence the error amplifier could now be a 20 dBm driver in a 10W system. Even a 10% efficient amplifier would add only 1W to the DC power reducing our amplifier from 40% to 38%. The main issue will however be the development of suitable wideband couplers and compensation for the different delays at each harmonic in the correction loop. The plan is to investigate this further, possibly through prototyping, to determine and quantify the practical advantages in canceling the harmonics in this manner.

Modulator Techniques

Many linearisation systems consider not just the amplifier but also the up converter or modulator and also include a receiver and feedback. The feedback can be Polar (magnitude and angle) or Cartesian (I/Q) in nature. The LINC Amplifier however uses non orthogonal equal magnitude vectors to generate the output signal.

Polar Loop Modulator

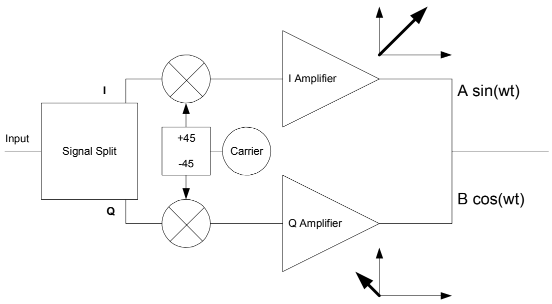
In the system the output amplitude and phase is compared to the input phase and amplitude and feedback loop is used to give the corrected output. In some cases raw amplitude and phase information is passed to the system and in others the system includes down converters on the sampling side of the amplifier.



Polar Loop Modulator Schematic

Cartesian Loop Modulator

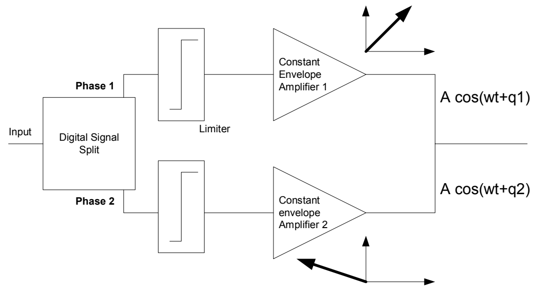
This is similar to the polar loop except Cartesian (I/Q) co-ordinates are used. A feedback mechanism can be used, where the output is passed to an IQ demodulator and the resultant IQ output is compared with the required input IQ.



Cartesian Loop Modulator Schematic

Linear Amplification by Non Linear Components (LINC)

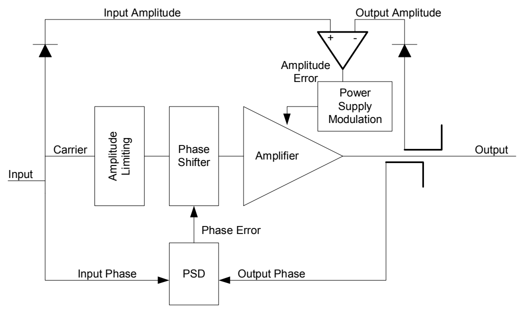
The LInear amplification using Non linear Components (LINC) is, to some extent, an expansion of the Cartesian loop idea, but where two constant envelope amplifiers are used. So the amplifiers are always working at high efficiency, but the two signals in the amplifiers are not orthogonal, hence the output signal has some amplitude modulation as well. This means that the two amplifiers can be working efficiently, but the overall system is not as the two signals do not, by design, combine orthogonally.



LINC Amplifier Schematic

Envelope Elimination and Recovery

This is similar to the Polar loop transmitter described earlier. The main difference is that the Power amplifier is used as an amplitude modulator. This means the amplifier is always in saturation and hence working most efficiently. This is achieved by modulating the power supply voltage.

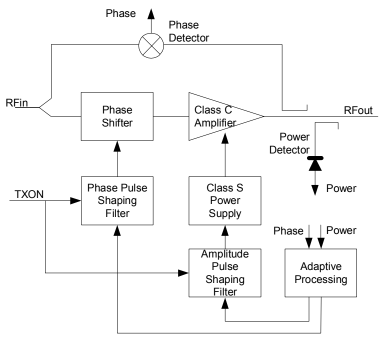


EE&R Amplifier Schematic

The main design challenge becomes the time constants and efficiency of the power supply modulator. In some systems (in handsets) the modulator is a simple resistive load and the efficiency of the overall system is good enough. Others use fast switched power supplies with variable output voltages with suitable time constants.

Research Results

The EE&R amplifier was researched in more detail. One advantage in RADAR is that we do not have an envelope to be eliminated, and we only need to maintain the signal magnitude at the output. So the circuit can be simplified with just a TXON control line instead of the input detector. A problem with the feedback loops is that during the receiver time, when there is no RF signal transmitted, the loop gain is zero and the loop can go out of balance. When the transmit pulse is present the loop now has to stabilise in a short time, this could introduce unwanted emissions. It may be possible to use a sample and hold technique for the duration of the TXON pulse, but this may be complicated to implement. Hence an open loop or adaptive technique was researched.

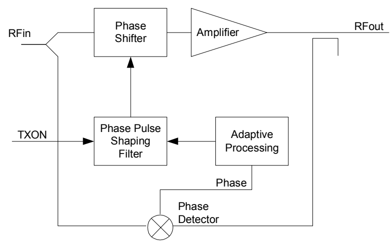


Phase Open Loop EE&R

The above figure shows a novel open loop method of EE&R amplifier. The phase shifter and power supply are now controlled by the TXON pulse, suitably filtered, or shaped to give the correct correction of the output signal. With this method, the output is monitored and the shaping filters adapted. A Class C amplifier is utilized because it is then possible to leave the power supply voltage on during the pulse as the current reduces as the RF power is turned off.

Phase Only Version

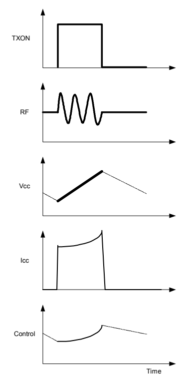
A simplification was also researched . In this novel method the complex power supply modulator is not implemented, and we accept the power droop in the pulse. We could however just correct the phase rotation during the pulse. In this method, the phase predistortion is not generated by the input RF signal, but by a control signal derived from the RADAR pulse controller. The pulse derived from detecting the RADAR pulse envelope or using a separate control system.



Phase Only System

Open Loop Control and Adaptation

In some SIEMENS GSM mobile phones the transmitter's output power is controlled by both a TXON pulse and also a digitally generated ramp function. This ramp function can be set by the phones software to control the turn on and turn off amplitude slopes. A similar system with some analogue filtering has been researched and proposed for Radar transmitter linearisation applications. The waveforms in the amplifier and the type of control signal are shown below.



Control Signal Waveforms

Conclusions and Recommendations

The extension of existing Radar system dynamic range would allow current sensors to see deeper into clutter (i.e., see small targets in the presence of large clutter levels e.g. urban clutter). The new dynamic range enhancement methods presented within this paper have direct relevance to military and telecommunications markets and applications.

This paper has presented the successful research work which has led to novel control methods for open loop type of Envelop Elimination and Recovery Technique (EE&R) amplifiers. The researched and presented methods provide a significant advantage in terms of amplitude and phase preservation in Class C amplifier stage for MESAR class Radar systems. The methods can also be applied to other amplifier Classes, but we conclude the principal benefit relates to Class C amplifiers for MESAR type Radar systems.

The successfully researched and presented methods provide a practical cost and performance sensitive solution to increase the transmitted pulse length and hence magnitude of target illumination, while simultaneously providing high Power Added Efficiency (PAE). The direct result of this increase is a significant enhancement in the dynamic range of the Radar system.

The innovative methods presented in the paper are sufficiently advanced for further practical development using bread-board prototyping techniques.

A Patent Application has been filed to protect the subject matter of this work.

Acknowledgements

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References

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