

Radartutorial

Book 4 “Radar Transmitter”

This educational endowment is a printable summary of the fourth chapter of the internet representation “Radar Basics” on www.radartutorial.eu , containing a lecture on the principles of radar technology.

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Learning Objectives:

This chapter describes the different types of transmitters used in radar sets. Upon completion of this chapter you will be able to:

- Describe the general task of and know the demands on a radar transmitter,
- State the meaning of the term “Coherence”
- Describe the general design of a fully-coherent radar transmitter and compare it with the general design of a pseudo-coherent radar transmitter.
- Describe the technology of Intra-pulse Modulation and the Pulse Compression.
- State the different methods of Intra-pulse Modulation.

Radar Transmitter

Tasks of a radar transmitter

The radar transmitter produces the short duration high-power RF pulses of energy that are radiated into space by the antenna. The radar transmitter is required to have the following technical and operating characteristics:

The transmitter must have the ability to generate the required mean RF power and the required peak power

- The transmitter must have a suitable RF bandwidth.
- The transmitter must have a high RF stability to meet signal processing requirements
- The transmitter must be easily modulated to meet waveform design requirements.
- The transmitter must be efficient, reliable and easy to maintain and the life expectancy and cost of the output device must be acceptable.

The radar transmitter is designed around the selected output device and most of the transmitter chapter is devoted to describing output devices therefore.

Division of radar transmitters

High-Power Oscillator as Transmitter

One main type of transmitters is the keyed-oscillator type. In this transmitter one stage or tube, usually a magnetron produces the RF pulse. The oscillator tube is keyed by a high-power dc pulse of energy generated by a separate unit called the modulator. This transmitting system is called **POT** (Power Oscillator Transmitter). Radar units fitted with a POT are either non-coherent or pseudo-coherent.

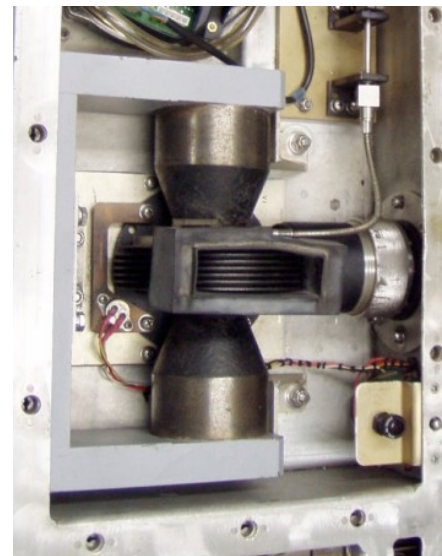


Figure 1: self-oscillating Transmitter using a Magnetron (ATC radar ASR-910)

High-Power Amplifier as Transmitter

Power-Amplifier-Transmitters (**PAT**) is used in many recently developed radar sets. In this system the transmitting pulse is caused with a small performance in a waveform generator. It is taken to the necessary power with an amplifier following (Amplifon, Klystron or Solid-State-Amplifier). Radar units fitted with a PAT are fully coherent in the majority of cases.

A special case of the PAT is the active antenna.

- Even every antenna element
 - or every antenna-group
- is equipped with an own amplifier here.

Solid-state transmit/receive modules appear attractive for constructing phased array radar systems. However, microwave tube technology¹ continues to offer substantial advantages in power output over solid-state technology.

¹ Microwave velocity modulated tubes are described in book 5.

The Concept of “Coherence”

Whether a radar set is coherent or non-coherent always depend on the transmitter. As a transmitter different systems are used in radar.

Non-coherent Radar Processing

One of the transmitting systems is the POT (Power Oscillator Transmitter) which is self oscillating. When such a device is switched on and off as a result of modulation by the rectangular modulating pulse, the starting phase of each pulse is not the same for the different successive pulses. The starting phase is a random function related to the start up process of the oscillator.

Note: Self oscillating transmitter gives random phase pulse to pulse and is *not* coherent!

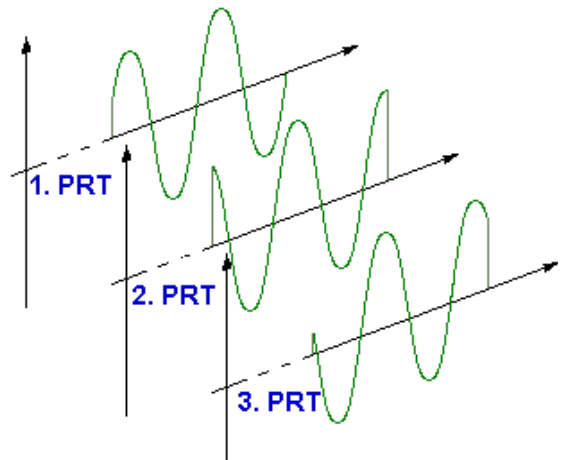


Figure 2: non-coherent radar processing: every pulse starts with a random phase

Coherent Radar Processing

Another transmitter-system is the PAT (Power-Amplifier-Transmitter). In this case, the high-power amplifier is driven by a highly stable continuous RF source, called the waveform generator. Modulating the output stage in response to the PRF does not affect the phase of the driver/RF source. Assuming the RF is a multiple of the PRF (as is normally the case), each pulse starts with the same phase. Systems, which inherently maintain a high level of phase coherence from pulse to pulse, are termed fully coherent. Note that phase coherence is maintained even if the PRF and RF are not locked together (provided the RF source is phase stable). As stated, it is common practice to lock the PRF to the RF phase and this assumption makes it easier to understand the concept of coherence.

Note: Low Power oscillator and amplifier give same phase pulse to pulse and are a coherent system!

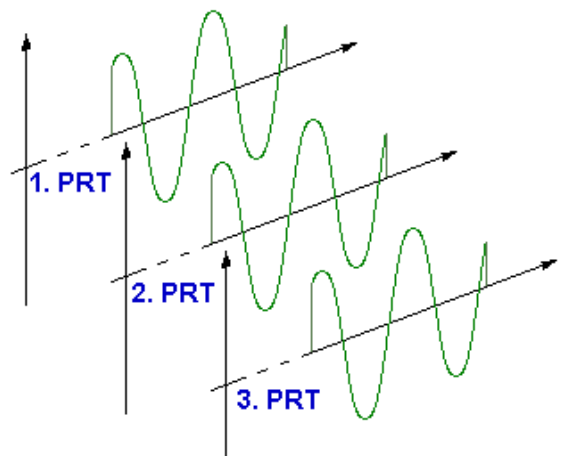


Figure 3: coherent radar processing: every pulse starts with the same phase

The most important benefit of this system is the ability to differentiate relatively small differences in velocity (which correspond to small differences in phase). This coherent target processing offers Doppler resolution/estimation and provides less interference and signal/noise benefits relative to non-coherent processing.

Pseudo-coherent Radar

A requirement for any Doppler radar is coherence; that is, some definite phase relationship must exist between the transmitted frequency and the reference frequency, which is used to detect the Doppler shift of the receiver signal. Moving objects are detected by the phase difference between the target signal and background clutter and noise components. Phase detection of this type relies on coherence between the transmitter frequency and the receiver reference frequency.

If the transmitter output stage is a self oscillating device, the pulse to pulse phase is random on transmission. In coherent detection, a stable CW reference oscillator signal, which is locked in phase with the transmitter during each transmitted pulse, is mixed with the echo signal to produce a beat or difference signal. Since the reference oscillator and the transmitter are locked in phase, the echoes are effectively compared with the transmitter in frequency and phase. This phase reference must be maintained from the transmitted pulse to the return pulse picked up by the receiver. Pseudo-coherent Radar sets are sometimes called: „coherent-on-receive“.

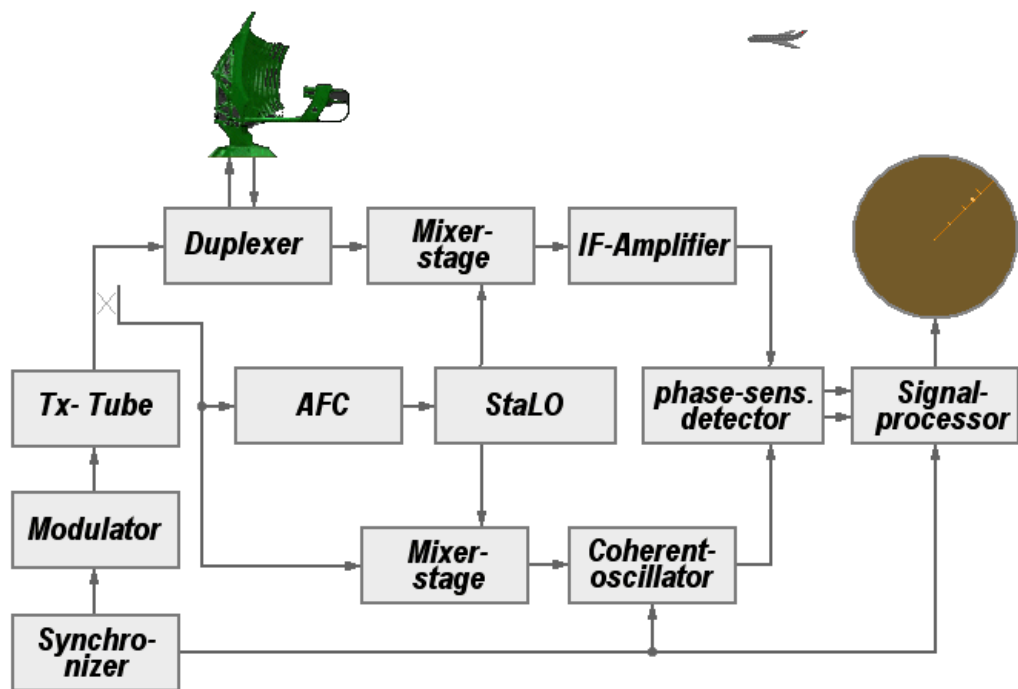


Figure 4: The principle of a pseudo-coherent radar.

- Synchronizer** The synchronizer supplies the synchronizing signals that time the transmitted pulses, the indicator, and other associated circuits.
- Modulator** The oscillator tube of the transmitter is keyed by a high-power dc pulse of energy generated by this separate unit called the modulator.
- Tx-Tube** The Tx-Tube is a self-oscillating tube generating high-power microwaves.
- Duplexer** The duplexer alternately switches the antenna between the transmitter and receiver so that only one antenna need be used. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver.
- Antenna** The Antenna transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception.
- Mixer stage** The function of the mixer stage is to convert the received rf energy to a lower, intermediate frequency (IF) that is easier to amplify and manipulate electronically. The intermediate frequency is usually 30 op to 74 megahertz. It is obtained by heterodyning the received signal with a local-oscillator signal in the mixer stage. The mixer stage converts the received signal to the lower IF signal without distorting the data on the received signal.

| | |
|--|--|
| IF-Amplifier | After conversion to the intermediate frequency, the signal is amplified in several IF-amplifier stages. Most of the gain of the receiver is developed in the IF-amplifier stages. The overall bandwidth of the receiver is often determined by the bandwidth of the IF-stages. |
| Mixer stage 2 | The directional coupler provides a sample of the transmitter output on every pulse. This signal adjusts the STALO frequency via the AFC but more importantly, it adjusts the phase of the COHO, locking it to the phase reference from the non-coherent transmitter. |
| Automatic Frequency Control (AFC) | <p>As in all superheterodyne receivers, controlling the frequency of the local oscillator keeps the receiver tuned. Since this tuning is critical, some form of automatic frequency control (afc) is essential to avoid constant manual tuning. Automatic frequency control circuits mix an attenuated portion of the transmitted signal with the local oscillator signal to form an IF signal. This signal is applied to a frequency-sensitive discriminator that produces an output voltage proportional in amplitude and polarity to any change in IF-frequency. If the IF signal is at the discriminator center frequency, no discriminator output occurs. The center frequency of the discriminator is essentially a reference frequency for the IF-signal.</p> <p>The output of the discriminator provides a control voltage to maintain the local oscillator at the correct frequency.</p> |
| Stable Local Oscillator (StaLO) | <p>As the receiver is normally a super heterodyne, a stable local oscillator known as the StaLO down converts the signal to intermediate frequency.</p> <p>Most radar receivers use a 30 up to 74 megahertz intermediate frequency. The IF is produced by mixing a local oscillator signal with the incoming signal. The local oscillator is, therefore, essential to efficient operation and must be both tunable and very stable. For example, if the local oscillator frequency is 3,000 megahertz, a frequency change of 0.1 percent will produce a frequency shift of 3 megahertz. This is equal to the bandwidth of most receivers and would greatly decrease receiver gain.</p> <p>The power output requirement for most local oscillators is small (20 to 50 milliwatts) because most receivers use crystal mixers that require very little power.</p> <p>The local oscillator output frequency must be tunable over a range of several megahertz in the 4,000-megahertz region. The local oscillator must compensate for any changes in the transmitted frequency and maintain a constant 30 up to 74 megahertz difference between the oscillator and the transmitter frequency. A local oscillator that can be tuned by varying the applied voltage is most desirable.</p> |
| Phase-sensitive detector | The IF-signal is passed to a phase sensitive detector (PSD) which converts the signal to base band, while faithfully retaining the full phase and quadrature information of the Doppler signal. This means, the phase-sensitive detector produces a video signal. The amplitude of the video signal is determined by the phase difference between the COHO reference signal and the IF echo signals. This phase difference is the same as that between the actual transmitted pulse and its echo. The resultant video signal may be either positive or negative. |
| Signal processor | The signal processor is that part of the system which separates targets from clutter on the basis of Doppler content and amplitude characteristics. |
| Directional Coupler | The directional coupler provides a sample of the transmitter output on every pulse. This signal adjusts the STALO frequency via the AFC but more importantly, it adjusts the phase of the COHO, locking it to the phase reference from the non-coherent transmitter (e.g. Magnetron). The phase synchronization of the COHO by means of a sample of the magnetron output is mandatory because there is no phase correlation between two successive RF pulses of the magnetron. |
| Coherent oscillator | The Coherent Oscillator (COHO) provides a low-power continuous RF-energy. It enables the down conversion process into the phase sensitive detector, whilst maintaining an accurate phase reference. The COHO lock pulse is originated by the transmitted pulse. It is used to synchronize the COHO to a fixed phase relationship with the transmitted frequency at each transmitted pulse. The COHO takes over the phase of the transmitter tube and provides it to the receiver part of the system. This is the reason why the pseudo-coherent radar is also called “coherent on receive”. |
| Indicator | The indicator should present to the observer a continuous, easily understandable, graphic picture of the relative position of radar targets. |

Disadvantages of the pseudo-coherent radar

The pseudo-coherent radar is a retired one today, but some older (or low-cost) radar sets are still operational. The disadvantages of the pseudo-coherent radar can be summarized as follows:

- The phase locking process is not as accurate as a fully coherent system, which reduces the MTI Improvement factor.
- This technique cannot be applied to frequency agile radar. Frequency change in a magnetron relies on the mechanical tuning of a cavity and it is essentially a narrow band device.
- It is not flexible and cannot easily accommodate changes in the PRF, pulsewidth or other parameters of the transmitted signal. Such changes are straightforward in fully coherent radar because they can be performed at low level. It is also impossible to perform FM modulation (which is mandatory for a pulse compression radar) with this type of system.
- Second time around echoes are returns from large fixed clutter areas located a long distance from the radar. Because they originate from a large distance, such echoes are returned after a second magnetron pulse has been transmitted. However, they pertain to the first pulse transmitted by the magnetron. Such echoes are range ambiguous but, in addition, second time around clutter will not cancel. This is due to the fact that the phase locking of the COHO applies only to the last transmitted pulse.

Modulator

Radio frequency energy in radar is transmitted in short pulses with time durations that may vary from 1 to 50 microseconds or more. A keyed oscillator transmitter needs a special modulator. This modulator produces impulses of high voltage switching the microwave tube on/off.

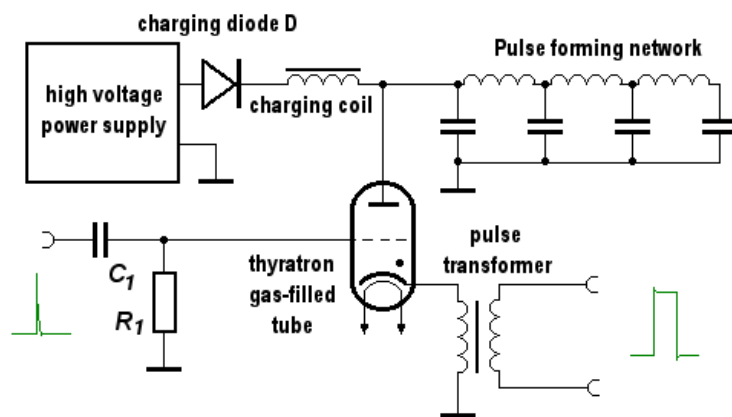


Figure 5: Thyatron Modulator



Figure 6: ancient modulator (Spoon Rest D) showing all components of a modulator

The hydrogen thyatron modulator is the most common radar modulator. It employs a pulse-forming network that is charged up slowly to a high value of voltage. The network is discharged rapidly through a pulse transformer by the thyatron keyed tube to develop an output pulse; the shape and duration of the pulse are determined by the electrical characteristics of the pulse-forming network and of the pulse transformer.

As circuit for storing energy the thyatron modulator uses essentially a short section of artificial transmission line which is known as the pulse-forming network (PFN). Via the charging path this PFN is charged on the double voltage of the high voltage power supply with help of the magnetic field of the charging impedance. Simultaneously this charging impedance limits the charging current. The charging diode prevents that the PFN discharge him about the intrinsic resistance of the power supply again.

The function of thyatron is to act as an electronic switch which requires a positive trigger of only 150 volts. The thyatron requires a sharp leading edge for a trigger pulse and depends on a sudden drop in anode voltage (controlled by the pulse-forming network) to terminate the pulse and cut off the tube. The R-C combination acts as a DC-shield and protect the grid of the thyatron. This trigger pulse initiates the ionization of the complete thyatron by the charging voltage. This ionization allows conduction from the charged pulse-forming network through pulse transformer. The output pulse is then applied to an oscillating device, such as a magnetron.

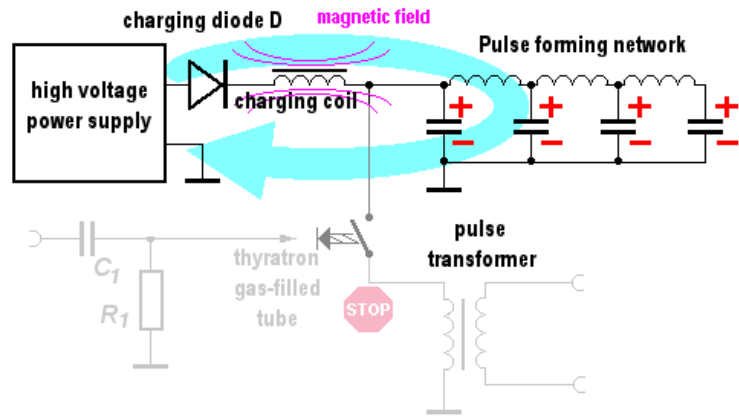


Figure 7: charging currents path

The Charge Path

The charge path includes the primary of the pulse transformer, the dc power supply, and the charging impedance. The thyatron (as the modulator switching device) is an open circuit in the time between the trigger pulses. Therefore it is shown as an open switch in the Figure.

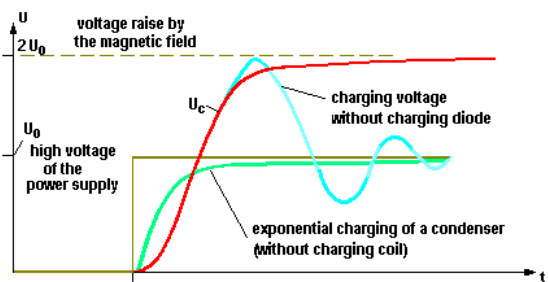


Figure 8: diagram of charging currents

Once the power supply is switched on (look at the dark green voltage jump in the following diagram), the current flows through the charging diode and the charging impedance, charges the condensers of the pulse forming network (PFN). The coils of the PFN are not yet functional. However, the induction of the charging impedance offers a great inductive resistance to the current and builds up a strong magnetic field. The charging of the condensers follows an exponential function (line drawing green). The self-induction of the charging impedance overlaps for this.

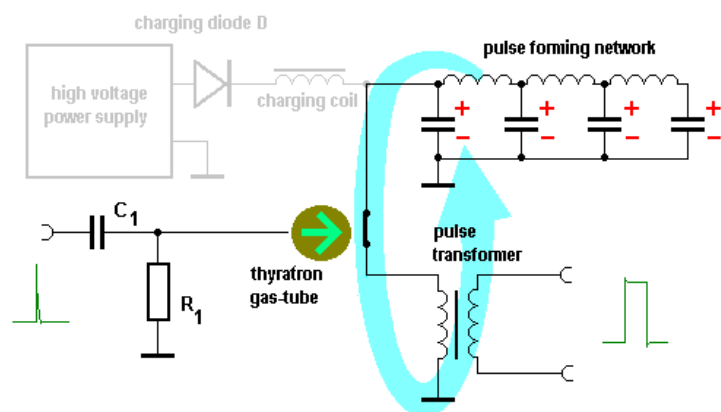


Figure 9: discharging currents path

The Discharge Path

When a positive trigger pulse is applied to the grid of the thyatron, the tube ionizes causing the pulse-forming network to discharge through the thyatron and the primary of the pulse transformer. (The thyatron is „fired“)

The fired thyatron grounds the pulse line at the charging coil and the charging diode effectively. Therefore, a current flows for the duration PW through the pulse transformer primary coil to ground and from ground through the thyatron, which is now

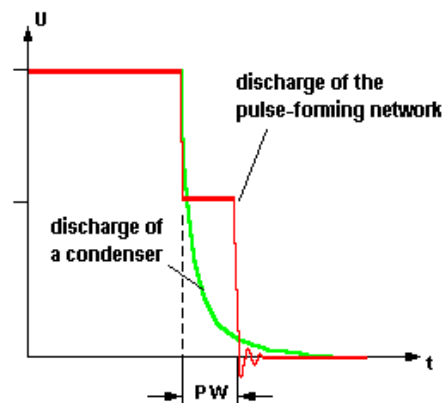


Figure 10: diagram of discharging currents

conducting to the other side of the pulse forming network. The high voltage pulse for the transmitting tube can be taken on the secondary coil of the pulse transformer. Exactly for this time an oscillating device swings on the transmit frequency. Because of the inductive properties of the PFN, the positive discharge voltage has a tendency to swing negative.

If the oscillator and pulse transformer circuit impedance is properly matched to the line impedance, the voltage pulse that appears across the transformer primary equals one-half the voltage to which the line was initially charged.

Thyratron

A typical thyratron is a gas-filled tube for radar modulators. The function of the high-vacuum tube modulator is to act as a switch to turn a pulse ON and OFF at the transmitter in response to a control signal.

The grid has complete control over the initiation of cathode emission for a wide range of voltages. The anode is completely shielded from the cathode by the grid. Thus, effective grid action results in very smooth firing over a wide range of anode voltages and repetition frequencies. Unlike most other thyratrons, the positive grid-control characteristic ensures stable operation. In addition, deionization time is reduced by using the hydrogen-filled tube.

A trigger pulse ionize the gas between the anode and the cathode. Only by removing the plate potential or reducing it to the point where the electrons do not have enough energy to produce ionization will tube conduction and the production of positive ions stop. Only after the production of positive ions is stopped will the grid be able to regain control.

Because of the very high anode voltage the anode is attached most on the upper end of the glass bulb. Therefore the tube looks very ancient. By the ionized gas it shines in the ionized condition like a glow lamp.



Figure 11: Thyratron

Note: The condensers in a modulator have got a high capacity. There are very high death-trap voltages retained after the off-switching of the device. During maintenance near the modulator, these condensers are to discharged!

Fully Coherent Radar

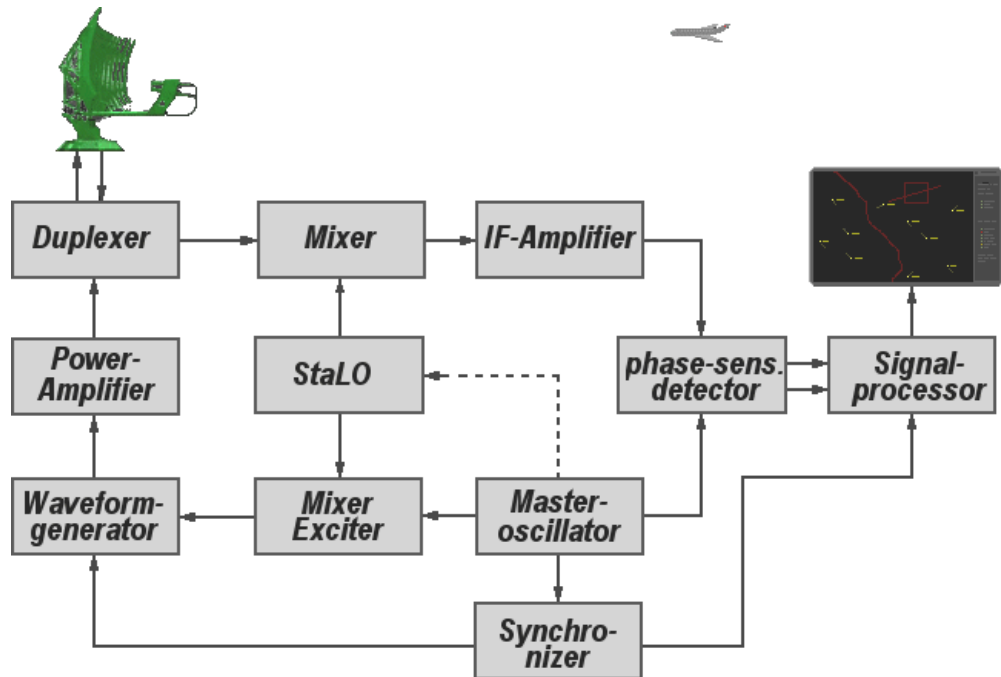


Figure 12: An easy block diagram of a fully coherent radar

The block diagram on the figure illustrates the principle of a fully coherent radar. The fundamental feature is that all signals are derived at low level and the output device serves only as an amplifier. All the signals are generated by one master timing source, usually a synthesiser, which provides the optimum phase coherence for the whole system. The output device would typically be a klystron, TWT or solid state. Fully coherent radars exhibit none of the drawbacks of the pseudo-coherent radars, which we studied in the previous section. Additional devices have the following function:

- Master Oscillator** The Master Oscillator is a very stable CW (Continuous Wave) crystal oscillator and constitutes the internal phase reference. It provides the coherent reference signal to the Phase Sensitive Detector and also through a frequency divider generates the system PRF in the Synchronizer.
- Mixer/ Exciter** The function of this mixer stage is to convert the StaLO- Frequency and the Master Oscillator frequency upwards into the phase-stabile continuous wave transmitter-frequency. Any changing of the operating frequency
- Waveform-Generator** The Waveform-Generator generates the transmitting pulse in low- power. It generates the transmitting signal on an IF- frequency. It permits generating predefined waveforms by driving the amplitudes and phase shifts of carried microwave signals. These signals may have a complex structure for a pulse compression. The IF-pulses are mixed with the Exciter frequency to the low-power microwave pulses.
- Power Amplifier** In this system the transmitting pulse is caused with a small performance in a waveform generator. It is taken to the necessary power with a Power Amplifier followingly. The Power Amplifier would typically be a klystron, Traveling Wave Tube (TWT) or solid state.

Solid State Transmitter

The PSR transmitter of the ATC-radar ASR-E (Manufacturer: EADS) operates in the S-Band (2.7 ... 2.9 GHz) and is solid state. It comprises four clusters, each of which contains eight power modules. All power modules are identical. BITE and status information are displayed on the transmitter front panel, as well as at the operator workstation. The modules can be replaced during transmitter operation (hot replacement) without the disconnection of any cables.



Figure 13: Solid state amplifier of the ATC-radar ASR-E (Manufacturer: EADS)

All high power transistors are protected against consequential damage. The availability of the transmitter is nearly 100% because of the graceful degradation capability. The unservicability of one or more power modules will not cause the complete loss of the transmitter and consequently of the ASR-E system. A temporary slight reduction in performance has, however, to be accepted. Driver and power supply modules are also redundant.

Power Modules

Solid State transmitters are employed in radar sets nowadays however too. At constant phases several MESFET- power amplifiers operates parallelly by means of simple power splitters and adders.

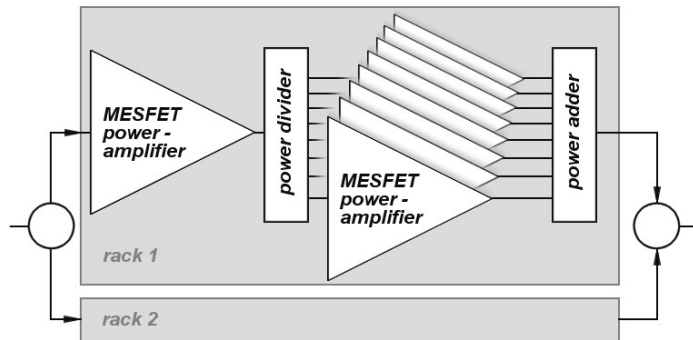


Figure 14: Schematic diagram of a power-module for solid-state transmitter

The high performance is assembled by many low-power amplifiers (or amplifier modules). The modules are feed in phase by power splitters. Its respective output powers then are in phase summed up to the complete transmit power. To achieve adequate range with relatively low pulse power, the pulses are intra-pulse modulated often. The technology of pulse compression we will discuss later.

GaAs-MESFETs are more often used by radar sets in solid state high power amplifiers. **MMIC**- technology (**M**onolithic **M**icrowave **I**ntegrated **C**ircuit) is a semiconductor process technology. It can be used to obtain active elements on the same silicon substrate. These circuits can be used up to very high frequencies.



Figure 15: GaAs-MeSFET Transistor in MMIC Technology

Waveform-Generator

A waveform generator generates the transmitting signal on an IF- frequency. It permits generating predefined waveforms by driving the amplitudes and phase shifts of carried microwave signals. These signals may have a complex structure for a pulse compression. Since these signals are used as a reference for the receiver channels too, there are high requirements for the frequency stability.

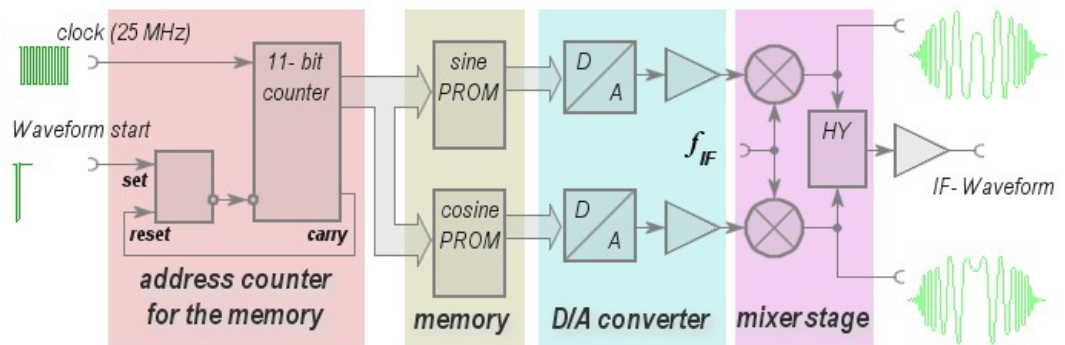


Figure 16: an e.g. Block diagram of a waveform generator for a non-linear compressed pulse

The finally waveform is constructed of 2048 discrete voltage steps here. Its values of amplitude and phase are stored in programmable memories (PROM's). The processing of an I & Q- phase-detector is arranged reverse virtually.

This method of design the transmitting pulses has got the advantage, that the waveform is digitally described for a computer-controlled signal processing. A digital processor unit can execute the pulse compression now.

| | |
|------------------------------|--|
| Clock-Pin | The external clock of 25 Megahertz clocks the counter-cascade. |
| WF-Start-Pin | The trailing edge of the negative polarized "WF-Start"-Pulse triggers the flip-flop. The output enables the counter-cascade. It begins to count the clock pulses. The flip-flop set by the „WF-Start“-Pulse generates an enable-signal for the counter-cascade. The carry-pulse of the counters resets the flip-flop and the counter stops. |
| 11-Bit Counter | The counter-cascade counts the clock pulses and generates the 11 adress bits for the memories. One loop of the counter-cascade stand for the pulsewidth of the transmitting pulse and take a time of approximately 40 microseconds. |
| Carry-Signal to Reset | The carry pulse of the counter-cascade resets the flip-flop and the counter stops to count. |
| 11-Bit Address-Bus | There are 11 adress bits for adressing the memories.. |
| Sine- PROM | The whole waveform is divided into 2048 timesteps. For every timestep a 8-bit voltage value is stored in this programmable memory. This memory provides the sine wave (the In-Phase signal). |
| Cosine- PROM | This memory provides the cosine wave (the Quadrature signal). |
| D/A- Converter | This D/A-Converter converts the 8-Bit data words into an analogue voltage. All these timesteps got an different value of voltage and these timesteps are stringed to a frequency together. The frequency can reach values from zero (DC) to 1 megahertz. |
| F1 Local Oszillator | This jack supplies with the unmodulated IF from an external F1 local oscillator. |
| Amplifier | This amplifier decouples the D/A-Converter from the load (the mixer). |
| Mixer | The mixer alloys the unmodulated IF-frequency and the frequencies of the modulation to the IF-Waveform. |
| Hybrid- Combiner | The Hybrid-Combiner is a passive power divider intrinsically, but used „on backwards“. The both input-signals are combined phase-dependent to the finally IF- waveform of the transmitting pulse. |
| Waveform- Amplifier | This amplifier is a decoupler and a band pass filter simultaneously to block out the harmonic waves. |

Pulse Compression

Intra-pulse modulation and pulse compression are generic terms that are used to describe a wave-shaping process that is produced as a propagating waveform, and is modified by the electrical network properties of the transmission line. The pulse is frequency or phase modulated, which provides a method to further resolve targets which may have overlapping returns. Pulse compression originated with the desire to amplify the transmitted impulse (peak) power by temporal compression. It is a method which combines the high energy of a long pulse width with the high resolution of a short pulse width. The pulse structure of a linear frequency modulated pulse is shown in the figure 17.

Since each part of the pulse has unique frequency, the returns can be completely separated.

This modulation or coding can be either

- FM (frequency modulation)
 - linear (chirp radar) or
 - non-linear as
 - symmetric form
 - non-symmetric form
- PM (phase coded modulation).

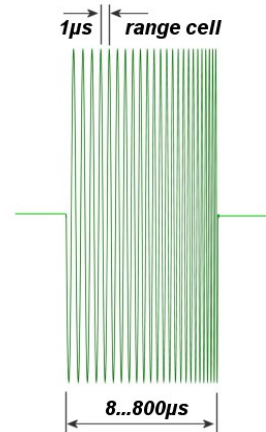


Figure 17: a linear frequency modulated pulse

Now the receiver is able to separate targets with overlapping of noise. The received echo is processed in the receiver by the compression filter. The compression filter readjusts the relative phases of the frequency components so that a narrow or compressed pulse is again produced. The radar therefore obtains a better maximum range than it is expected because of the conventional radar equation.

The ability of the receiver to improve the range resolution over that of the conventional system is called the pulse compression ratio (PCR). For example a pulse compression ratio of 50:1 means that the system range resolution is reduced by 1/50 of the conventional system.

Alternatively, the factor of improvement is given the symbol PCR, which can be used as a number in the range resolution formula, which now becomes:

$$R_{res} = c_0 \cdot Pw \cdot (2 \cdot PCR) \quad (1)$$

The compression ratio is equal to the number of sub pulses in the waveform, i.e., the number of elements in the code. The range resolution is therefore proportional to the time duration of one element of the code. The maximum range is increased by the PCR.

The minimum range is not improved by the process. The full pulse width still applies to the transmission, which requires the duplexer to remained aligned to the transmitter throughout the pulse. Therefore Rmin is unaffected.

Advantages

- lower pulse-power
- higher maximum range
- good range resolution
- better jamming immunity
- difficulty reconnaissance

Disadvantages

- high wiring effort
- bad minimum range
- time-sidelobes
- needs higher processing power

Pulse compression with linear FM waveform

At this pulse compression method the transmitting pulse has a linear FM waveform. This has the advantage that the wiring still can relatively be kept simple. However, the linear frequency modulation has the disadvantage that jamming signals can be produced relatively easily by so-called „Sweeper“.

The block diagram on the picture illustrates, in more detail, the principles of a pulse compression filter.

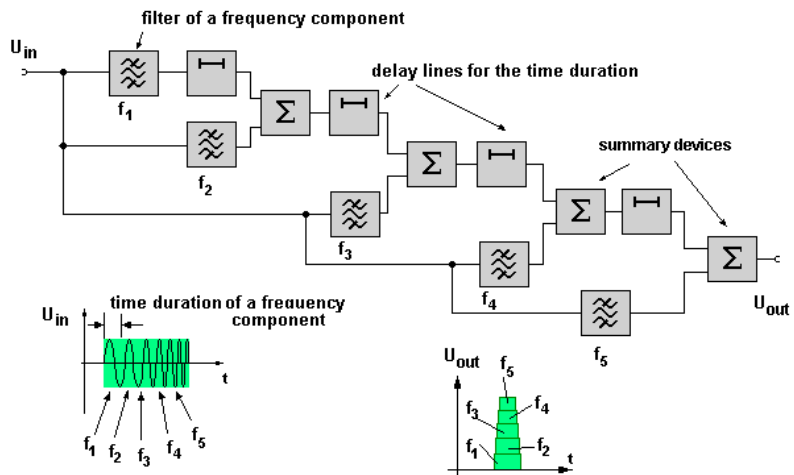


Figure 17: Block diagram for an analogue pulse-compression wiring

The compression filter are simply dispersive delay lines with a delay, which is a linear function of the frequency. The compression filter allows the end of the pulse to „catch up“ to the beginning, and produces a narrower output pulse with a higher amplitude. As an example of an application of the pulse compression with linear FM waveform the air defence radar family of AN/FPS-117 can be mentioned.

Filters for linear FM pulse compression radars are now based on two main types.

- Digital processing (following of the A/D- conversion).
- Surface acoustic wave (SAW) devices.

SAW- Devices

SAW devices (Surface Acoustic Wave) are extensively deployed in currently using the pulse compression operational systems. They are built on a piezoelectric substrate, which propagates acoustic waves along the surface.

The low speed of the waves means that significant delays can be implemented in a small space. The inter digital transducers convert the electrical signal to acoustic waves and are made of metallic thin films deposited on the substrate. It is clearly easy to fabricate the required shapes by photographic etching techniques. The frequency response of the delay line depends on the spacing of these transducers.

In the example shown, the received pulse is input at the left hand and the compressed output pulse results at the right hand end. The highest frequency suffers the largest delay and overlays the lowest frequency. All frequency parts of the input signal are slid into the same Rangecell.

The presence of harmonics in the signal input will hamper the output waveform of each filter. The output of the compression filter consists of the compressed pulse accompanied by responses at other times (i.e., at other ranges), called time or range sidelobes. SAW- Filter (Surface Acoustic Wave) werden oft in Radarsystemen mit Pulskompression eingesetzt und komprimieren das frequenzmodulierte Echosignal auf analogem Wege

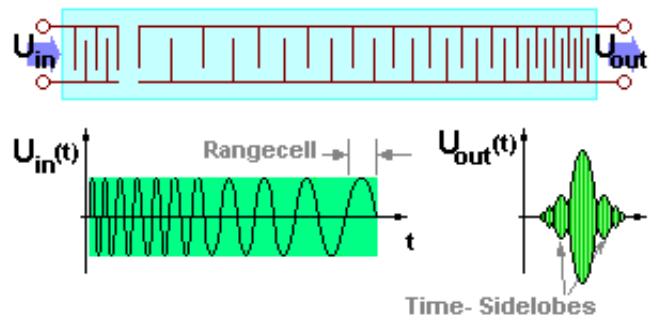


Figure 18: SAW- device width linear decreased spacing of the transducers

Time-Side-Lobes

The output of the compression filter consists of the compressed pulse accompanied by responses at other times (i.e., at other ranges), called time or range sidelobes. The figure shows a view of the compressed pulse of a chirp radar at an oscilloscope and at a ppi-scope sector.

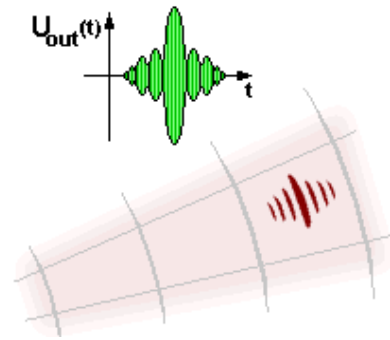


Figure 19: View of the Time-Side-Lobes

Amplitude weighting of the output signals may be used to reduce the time sidelobes to an acceptable level. Weighting on reception only results a filter „mismatch“ and some loss of signal to noise ratio.

The sidelobe levels are an important parameter when specifying a pulse compression radar. The application of weighting functions can reduce time sidelobes to the order of 30 db's.

Pulse compression with non-linear FM waveform

The non-linear FM waveform has several distinct advantages. The non-linear FM waveform requires no amplitude weighting for time-sidelobe suppression since the FM modulation of the waveform is designed to provide the desired amplitude spectrum, i.e., low sidelobe levels of the compressed pulse can be achieved without using amplitude weighting.

Matched-filter reception and low sidelobes become compatible in this design. Thus the loss in signal-to-noise ratio associated with weighting by the usual mismatching techniques is eliminated.

A symmetrical waveform has a frequency that increases (or decreases) with time during the first half of the pulse and decreases (or increases) during the last half of the pulse. A non symmetrical waveform is obtained by using one half of a symmetrical waveform.

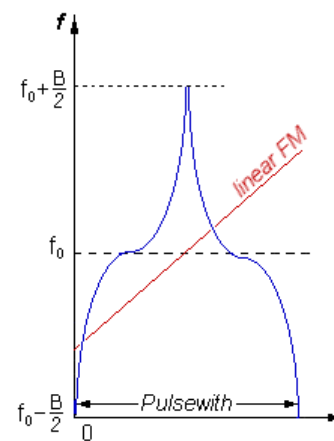


Figure 20: symmetric form

The disadvantages of the non-linear FM waveform are

- Greater system complexity
- The necessity for a separate FM modulation design for each type of pulse to achieve the required sidelobe level.

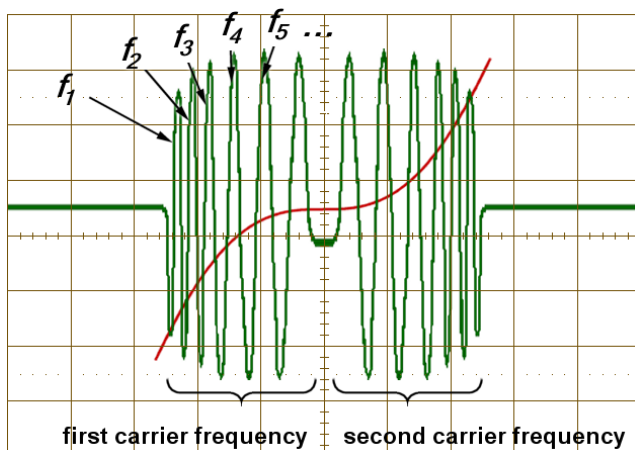


Figure 22: non-symmetric waveform divided for two carrier frequencies

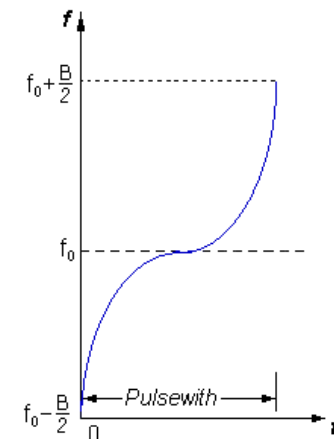


Figure 21: non-symmetric form

Phase-Coded Pulse Compression

Phase-coded waveforms differ from FM waveforms in that the long pulse is sub-divided into a number of shorter sub pulses. Generally, each sub pulse corresponds with a range bin. The sub pulses are of equal time duration; each is transmitted with a particular phase. The phase of each sub-pulse is selected in accordance with a phase code. The most widely used type of phase coding is binary coding..

The binary code consists of a sequence of either +1 and -1. The phase of the transmitted signal alternates between 0 and 180° in accordance with the sequence of elements, in the phase code, as shown on the figure. Since the transmitted frequency is usually not a multiple of the reciprocal of the sub pulsewidth, the coded signal is generally discontinuous at the phase-reversal points.

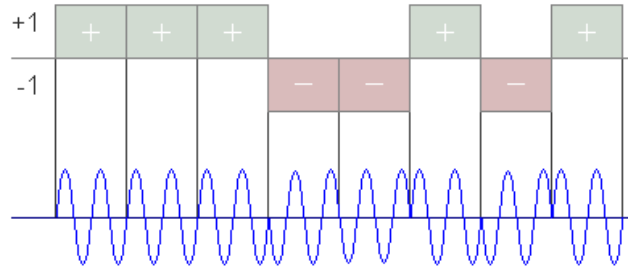


Bild 22: Diagramm eines Phasencodierten Sendeimpulses

The selection of the so called random 0, π phases is in fact critical. A special class of binary codes is the optimum, or Barker, codes. They are optimum in the sense that they provide low sidelobes, which are all of equal magnitude. Only a small number of these optimum codes exist. They are shown on the beside table. A computer based study searched for Barker codes up to 6000, and obtained only 13 as the maximum value.

It will be noted that there are none greater than 13 which implies a maximum compression ratio of 13, which is rather low. The sidelobe level is -22.3 db.

| Length of code n | Code elements | Peak-sidelobe ratio, dB |
|------------------|--------------------|-------------------------|
| 2 | + - | -6.0 |
| 3 | ++ - | -9.5 |
| 4 | ++ - + , +++ - | -12.0 |
| 5 | +++ - + | -14.0 |
| 7 | +++ -- + - | -16.9 |
| 11 | +++ ---- ++ --+ - | -20.8 |
| 13 | +++++ --++ - + - + | -22.3 |