IEC 62803-2

Edition 1.0 2024-08

INTERNATIONAL STANDARD

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Transmitting and receiving equipment for radiocommunication – Frequency response of optical-to-electric conversion device in high-frequency radio-over-fibre systems –
Part 2: Measurement method of common-mode rejection ratio of optical coherent detection device for radio-over-fibre transmitter

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INTERNATIONAL
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TRANSMITTING AND RECEIVING EQUIPMENT FOR RADIOCOMMUNICATION – FREQUENCY RESPONSE OF OPTICAL-TO-ELECTRIC CONVERSION DEVICE IN HIGH-FREQUENCY RADIO-OVER-FIBRE SYSTEMS –

Part 2: Measurement method of common-mode rejection ratio of optical coherent detection device for radio-over-fibre transmitter

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The text of this International Standard is based on the following documents:

Draft	Report on voting
103/269/FDIS	103/274/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62803 series, published under the general title *Transmitting and receiving equipment for radiocommunication – Frequency response of optical-to-electric conversion device in high-frequency radio-over-fibre systems* can be found on the IEC website.

Future documents in this series will carry the new general title as cited above. Titles of existing documents in this series will be updated at the time of the next edition.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

A variety of photonic devices operated in microwave and millimetre-wave bands are useful for an optical fibre transport system as well as wireless communication and broadcasting systems. An optical-to-electric conversion device including an optical receiver plays as an interface, which converts an optical signal into an electrical signal directly.

Microwave and millimetre-wave radio-over-fibre (RoF) systems are comprised mainly of two parts: an RF to photonic converter (E/O) and a photonic to RF converter (O/E). Radio waves are converted into an optical signal at the E/O, and the signal is transferred through the optical fibre, and then the radio waves are regenerated at the O/E.

A variety of photonic devices which carry microwave and millimeter-wave signals at subcarrier frequencies are used for high-frequency RoF systems. In high-frequency RoF systems such as millimetre-wave band radio signal transfer systems, the specifications of conversion efficiency and its frequency response have been important technical parameters, and therefore, the IEC 62803 series has been developed. Nowadays, the coherent optical fibre network system is used widely, namely in core and metro networks with a capacity greater than 100 Gbit/s/ch. Finally, cost and performance have improved. In this coherent optical fibre network system, an optical coherent detection device, which is comprised of an optical 90° hybrid coupler and balanced photodetectors, provides an IQ separation in an optical domain for easy digital signal processing. This detection device can be useful not only for the coherent optical signal transport but also for a millimeter-wave RoF system with high signal quality. To achieve a high signal quality, which means a good suppression of noises, a common-mode rejection ratio is a key parameter of the optical coherent detection. This document has been developed to provide to the industry a measurement method of a coherent optical detection device for evaluating the specifications to be used in high-frequency RoF systems, as well as in an optical coherent transport system. This document defines the measurement method of a common-mode rejection ratio, which has a significant impact on the performance of RoF systems.

TRANSMITTING AND RECEIVING EQUIPMENT FOR RADIOCOMMUNICATION – FREQUENCY RESPONSE OF OPTICAL-TO-ELECTRIC CONVERSION DEVICE IN HIGH-FREQUENCY RADIO-OVER-FIBRE SYSTEMS –

Part 2: Measurement method of common-mode rejection ratio of optical coherent detection device for radio-over-fibre transmitter

1 Scope

This part of IEC 62803 provides the measurement method of the common-mode rejection ratio of optical coherent detection devices in high-speed RoF systems, as well as in high-speed optical signal transmission systems. In addition, the method is also effective for the estimation of the detailed frequency response of the common-mode rejection ratios and O/E conversion efficiency. The method applies for the following:

– frequency range: 1 GHz to 110 GHz;
– wavelength band: 0,8 µm to 2,0 µm.

The use of optical coherent detection devices for high-speed RoF system is shown in Annex A as an example.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
common-mode rejection ratio
ratio between the signal powers of differential signals and common-mode signals

3.1.2
two-tone lightwave
lightwave that contains two dominant spectral components whose power difference is relatively small and frequency separation is stable

3.1.3
carrier-suppressed
situation when an MZM is biased at its minimum transmission point, the non-modulated carrier lightwave transmitted through and the two arms of the MZM are cancelled with each other at the output coupler

3.2 Abbreviated terms

CMRR	common-mode rejection ratio
DUT	device under test
E/O	electrical-to-optical
IF	intermediate frequency
LD	laser diode
LO	local oscillator
MZM	Mach-Zehnder interferometer-type intensity modulator
SIG	signal

4 Optical coherent detection device

4.1 General

4.1.1 Configuration

A coherent detection device has a 90° optical hybrid coupler with two balanced photodiodes. Two optical input signals as an optical signal and an optical local oscillator are mixed with a phase difference of 90° in the coupler, and then, interference of two signals is input into a balanced photodiode to generate an in-phase and a quadrature phase component of the signal.

4.1.2 Component parts

The optical coherent detection device consists of basic parts as follows:

- 90° optical hybrid coupler;
- balanced photodiode;
- input fibre pigtails (where appropriate);
- input receptacles (where appropriate);
- output RF ports (where appropriate);
- photodiode bias electrode (where appropriate);
- transimpedance amplifier (where appropriate);
- impedance matching resistor (where appropriate).

4.1.3 Structure

The structure is as follows (see Figure 1):

- optical input: fibre pigtail or receptacle;
- output RF port: coaxial connector, microstrip line, coplanar waveguide, etc.;
- options: bias electrode, transimpedance amplifier, impedance-matching resistor.

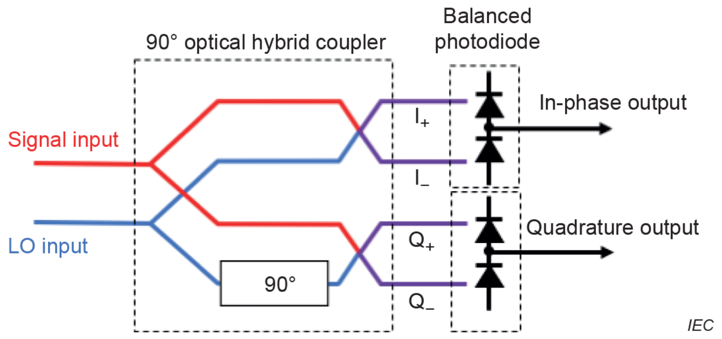


Figure 1 – Optical coherent detection device

4.2 Optical coherent detection device

4.2.1 General

This method is based on an optical phase delay to tune the phase difference of 90° in the 90° optical hybrid section and is based on a heterodyne detection in a balanced detection manner in the balanced photodiode section. The materials that should be used for the 90° optical hybrid and balanced photodiode are specified in 4.2.2 and 4.2.3.

4.2.2 Material of 90° optical hybrid

The main materials should be free-space optical circuits or photonic integrated circuits made with SiO_2, Si, SiN, GaAs, InP and InGaAs.

4.2.3 Material of balanced photodiode

The main materials of the photodiodes should be Si, GaAs, and InGaAs.

5 Sampling for quality control

5.1 Sampling

A statistically significant sampling plan shall be agreed upon between the user and supplier. Sampled devices shall be randomly selected and representatives of the production population shall satisfy the quality assurance criteria using the proposed test methods.

5.2 Sampling frequency

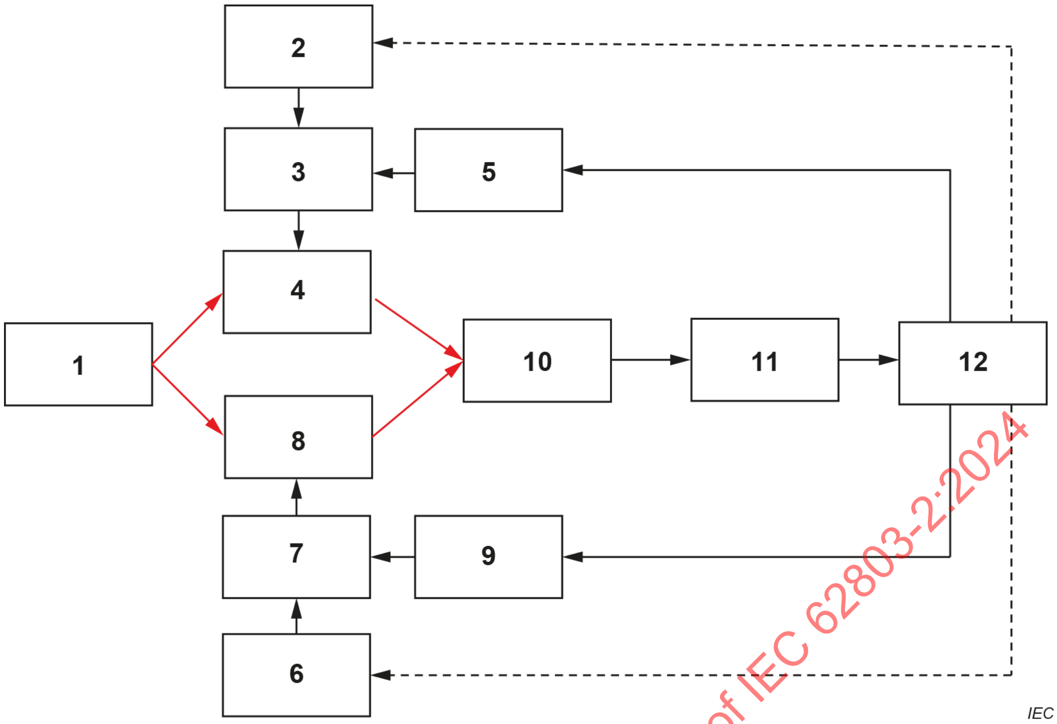
The appropriate statistical methods shall be applied to determine adequate sample size and acceptance criteria for the considered lot size. In the absence of more detailed statistical analysis, the following sampling plan can be employed:

Common-mode rejection ratio: two units at least per manufacturing lot.

6 Measurement method of common-mode rejection ratio

6.1 Circuit diagram

See Figure 2.



Key

1 laser diode

2 DC voltage source 1

3 bias tee 1

4 optical Mach-Zehnder interferometer-type intensity modulator 1

5 microwave signal source 1

6 DC voltage source 2

7 bias tee 2

8 optical Mach-Zehnder interferometer-type intensity modulator 2

9 microwave signal source 2

10 DUT

11 electrical spectrum analyser

12 personal computer

Red solid arrows = optical fibre cable

Black solid arrows = electrical wire cable

Black dashed arrows = interconnection cable

Figure 2 – Circuit diagram

6.2 Circuit description and requirements

The circuit description and requirements are given in the key to Figure 2.

6.3 Measurement conditions

6.3.1 Temperature and environment

The measurement should be carried out in a room with a temperature ranging from 5 °C to 35 °C. If the operation temperature ranges of the measurement apparatus are narrower than the above range, the specifications of the measurement apparatus should be followed. It is desirable to control the measurement temperature within ±5 °C in order to suppress the influence of the temperature drift of the measurement apparatus to a minimum. The temperature of the DUT can be changed using a temperature controller to verify the temperature dependence of the measured parameters, as necessary.

6.3.2 Warming-up of measurement equipment

The warming-up time shall be kept to typically 60 min, or the time written in the specifications of the measurement equipment or systems. Moreover, the warming-up time should be taken to be the longest among all of the measurement equipment.

6.4 Principle of measurement method

6.4.1 General

The method described here is based on the heterodyne principle. Two two-tone lightwave signals with frequency separations of $\omega_{RF} - \Delta$ and $\omega_{RF} + \Delta$, whose symbols are denoted in 6.4.2, induces frequency downconversion in the balanced photodiodes to separate the signal component, local oscillator (LO) component, and common-mode components. The ratio between these components provides the CMRR related to the signal (SIG) path and the LO path. By changing the frequency difference between the two-tone lightwave signals, the frequency response of the CMRR of the DUT is obtained.

6.4.2 Mathematical expressions of basic measurement principle

As is well known, an optical output from a Mach-Zehnder-interferometer-type optical intensity modulator (MZM), which is utilized as a two-tone lightwave signal generator, with a monotone RF signal modulation, can be expressed by

$$E = \sum_{n=-\infty}^{\infty} E_n e^{i(\omega_n t + \phi_n)} \text{ and } \omega_{RF} = \omega_{n+1} - \omega_n, \tag{1}$$

where E and ω_{RF} denote an electric field of the optical signal and an angular frequency of the modulating RF signal that corresponds to the angular frequency difference between adjacent optical tones, respectively. The two-tone lightwave signal generation based on carrier-suppressed double-sideband modulation by the MZM, under a bias voltage set to a minimum transmission point in the interferometer transfer function, has the following relationships:

$$|E_{-1}| = |E_1| \gg |E_n| \ (n \neq \pm 1), \text{ and} \tag{2}$$

$$E_n \propto J_n\left(A_{RF}\right) e^{i(\omega_0 - (-1)^n \omega_{RF})t + i\phi_0} \ (n = 1, -1) \tag{3}$$

where J_n, A_{RF}, ω_0, and ϕ_0 denote a Bessel function, an amplitude coefficient of the monotone RF signal at a frequency of ω_{RF}, an angular frequency of the lightwave input into the modulator, and a relative phase of the lightwave signal input into the modulator, respectively.

In the method, two two-tone lightwaves with the angular frequency separation of $\omega_{RF} - \Delta$ and $\omega_{RF} + \Delta$ are input into the SIG and LO ports of a coherent receiver system as a DUT, with the expression of

$$J_{-1}(A_{SIG})e^{i\left(\omega_0 - \frac{\omega_{RF}-\Delta}{2}\right)t} + E_{SIG0}e^{i\omega_0 t} + J_1(A_{SIG})e^{i\left(\omega_0 + \frac{\omega_{RF}-\Delta}{2}\right)t} = E_{SIG0}e^{i\omega_0 t} + 2ie^{i\omega_0 t}E_{SIG}\sin\frac{\omega_{RF}-\Delta}{2}t \quad \text{for SIG and} \tag{4}$$

$$J_{-1}(A_{LO})e^{i\left(\omega_0 - \frac{\omega_{RF}+\Delta}{2}\right)t} + E_{LO0}e^{i\omega_0 t} + J_1(A_{LO})e^{i\left(\omega_0 + \frac{\omega_{RF}+\Delta}{2}\right)t} = E_{LO0}e^{i\omega_0 t} + 2ie^{i\omega_0 t}E_{LO}\sin\frac{\omega_{RF}+\Delta}{2}t \quad \text{for LO,} \tag{5}$$

where E_{SIG0} and E_{LO0} denote an electrical field at a carrier frequency for the SIG and LO, respectively. In the DSB modulation condition, E_{SIG0} and E_{LO0} would be vanished. When a coupling ratio and an output phase imbalance of the output coupler in the 90° optical hybrid are γ:1 − γ (0 ≤ γ < 1) and ϕ ($\phi \sim \pi$), the output electric field of the hybrid for I_+ and I_- in Figure 1 can be expressed by

$$\left|\gamma 2ie^{i\omega_0 t}E_{SIG}\sin\frac{\omega_{RF}-\Delta}{2}t + (1-\gamma)2ie^{i\omega_0 t}E_{LO}\sin\frac{\omega_{RF}+\Delta}{2}t\right|^2 \quad \text{for } I_+ \text{ and} \tag{6}$$

$$\left|(1-\gamma)2ie^{i\omega_0 t}E_{SIG}\sin\frac{\omega_{RF}-\Delta}{2}t + \gamma e^{i\phi}2ie^{i\omega_0 t}E_{LO}\sin\frac{\omega_{RF}+\Delta}{2}t\right|^2 \quad \text{for } I_- \tag{7}$$

A balanced photodiode has two photodiodes with the difference between I_+ and I_- components. The conversion efficiency imbalance χ: 1 − χ (0 ≤ χ < 1) of these photodiodes induces the imbalanced output of the photodiodes. The output power of the photodiode for I_+ and I_- converts the electrical field to the power by $P \propto |E|^2$, where P and E denote the output power and the input electric field, respectively. Therefore, the resultant output signal can be expressed by

$$\chi\left|\gamma 2ie^{i\omega_0 t}E_{SIG}\sin\frac{\omega_{RF}-\Delta}{2}t + (1-\gamma)2ie^{i\omega_0 t}E_{LO}\sin\frac{\omega_{RF}+\Delta}{2}t\right|^2 - (1-\chi)\left|(1-\gamma)2ie^{i\omega_0 t}E_{SIG}\sin\frac{\omega_{RF}-\Delta}{2}t + \gamma e^{i\phi}2ie^{i\omega_0 t}E_{LO}\sin\frac{\omega_{RF}+\Delta}{2}t\right|^2 \tag{8}$$

In general, a photodiode has a limited bandwidth less than 1 THz. Thus, the components by the conversion at the high frequency are detected as a DC component. Finally, the output signal from the balanced photodiode in the RF domain can be expressed by

$$\begin{aligned}&2\left(\left(\chi-1\right)+2\left(1-\chi\right)\gamma+\left(2\chi-1\right)\gamma^2\right)E_{\mathrm{SIG}}^2+2\left(\chi-2\chi\gamma+\left(\left(1+e^{i\phi}\right)\chi-e^{i\phi}\right)\right)E_{\mathrm{LO}}^2\\&-2\left(\left(\chi-1\right)+2\left(1-\chi\right)\gamma+\left(2\chi-1\right)\gamma^2\right)E_{\mathrm{SIG}}^2\cos\left(\omega_{\mathrm{RF}}-\Delta\right)t\\&-2\left(\chi-2\chi\gamma+\left(\left(1+e^{i\phi}\right)\chi-e^{i\phi}\right)\right)E_{\mathrm{LO}}^2\cos\left(\omega_{\mathrm{RF}}+\Delta\right)t\\&+4\left(\left(1+e^{i\phi}\right)\chi+e^{i\phi}\right)\gamma\left(1-\gamma\right)E_{\mathrm{SIG}}E_{\mathrm{LO}}\left(\cos\omega_{\mathrm{RF}}t-\cos\Delta t\right)\end{aligned} \quad (9)$$

The differential mode, which is a necessary component, is obtained with a cross-product of $E_{\mathrm{LO}}E_{\mathrm{SIG}}$ at a frequency of ω_{RF}. On the contrary, components at frequencies of $\omega_{\mathrm{RF}} - \Delta$ and $\omega_{\mathrm{RF}} + \Delta$, are a leakage signal from the SIG and LO input to the balanced output. The ratio between the differential mode at a frequency of ω_{RF} and leakage components at frequencies of $\omega_{\mathrm{RF}} - \Delta$ and $\omega_{\mathrm{RF}} + \Delta$ is a common-mode rejection ratio (CMRR) for the SIG and the LO. The expressions are as follows.

$$4\left(\left(1+e^{i\phi}\right)\chi+e^{i\phi}\right)\gamma\left(1-\gamma\right)E_{\mathrm{SIG}}E_{\mathrm{LO}}+2\left(\left(\chi-1\right)+2\left(1-\chi\right)\gamma+\left(2\chi-1\right)\gamma^2\right)E_{\mathrm{SIG}}^2 \quad \text{for CMRR-SIG} \quad (10)$$

and

$$4\left(\left(1+e^{i\phi}\right)\chi+e^{i\phi}\right)\gamma\left(1-\gamma\right)E_{\mathrm{SIG}}E_{\mathrm{LO}}+2\left(\chi-2\chi\gamma+\left(\left(1+e^{i\phi}\right)\chi-e^{i\phi}\right)\right)E_{\mathrm{LO}}^2 \quad \text{for CMRR-LO} \quad (11)$$

In the ideal case under the condition that the coupling ratio γ = 0,5, the output phase imbalance ($\phi = \pi$), and the conversion efficiency imbalance χ = 0,5, the CMRRs are vanished. The fluctuation of these parameters is caused by the fabrication and assembling errors of the device. Finally, the CMRRs in the actual devices are induced.

6.4.3 Principle of measurement of common-mode rejection ratio

Figure 3 shows a schematic illustration of the electrical power spectra obtained at the output of the balanced photodiode. When the measured electrical powers of the differential mode and unwanted leakage components at frequencies of ω_{RF}, $\omega_{\mathrm{RF}} - \Delta$ and $\omega_{\mathrm{RF}} + \Delta$ are P_{DIFF}, P_{SIG}, and P_{LO}, the CMRR for the SIG and LO ports is expressed by $P_{\mathrm{DIFF}} - P_{\mathrm{SIG}}$ and $P_{\mathrm{DIFF}} - P_{\mathrm{LO}}$, respectively. The unwanted components at frequencies of $\frac{\omega_{\mathrm{RF}}}{2}$, $\frac{\omega_{\mathrm{RF}}-\Delta}{2}$, and $\frac{\omega_{\mathrm{RF}}+\Delta}{2}$ can also be observed. These components are caused by the existence of the laser carrier component: insufficient suppression of the carrier component by the DSB modulation.

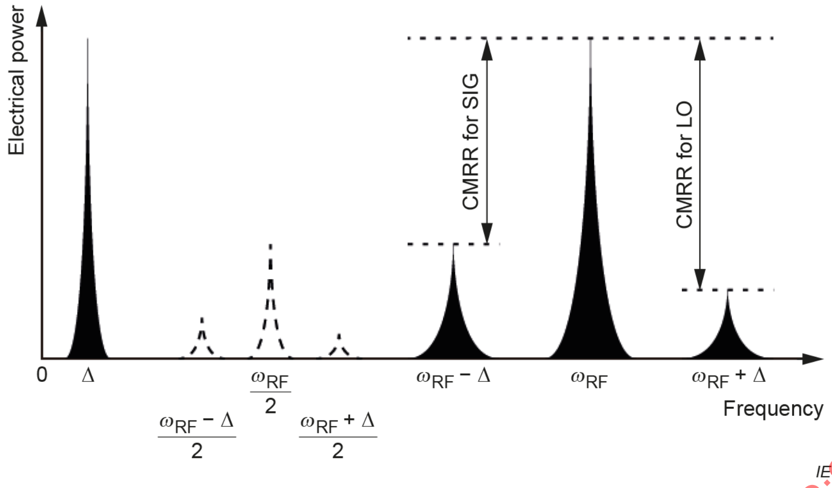


Figure 3 – Schematic illustration of the electric power spectra of the signal measured by the electrical spectrum analyser

6.5 Measurement procedure

The measurement procedure is as follows:

STEP 1) A laser diode, photodiode and electrical spectrum analyser are activated.

STEP 2) The target frequency f and frequency detuning Δf are decided. Typically, Δf should be less than 1 MHz.

STEP 3) The output ports of the optical Mach-Zehnder interferometer-type intensity modulators 1 and 2 are connected to the SIG and LO ports of the DUT.

STEP 4) The frequencies of microwave signal sources 1 and 2 are set to $\frac{f-\Delta f}{2}$ and $\frac{f+\Delta f}{2}$, respectively.

STEP 5) The amplitudes of microwave signal sources 1 and 2 are set to double the half-wave voltage of the optical Mach-Zehnder interferometer-type intensity modulators 1 and 2, respectively.

STEP 6) The output voltages of DC voltage sources 1 and 2 are set to the realization of the DSB modulation of the optical Mach-Zehnder interferometer-type intensity modulators 1 and 2, respectively. For optimization of the output voltages, the components at frequencies of $\frac{f-\Delta f}{2}$ and $\frac{f+\Delta f}{2}$ can be minimized using the electrical spectrum analyser.

STEP 7) The electrical power at frequencies of f, $\frac{f-\Delta f}{2}$, and $\frac{f+\Delta f}{2}$ is measured with P_{DIFF}, P_{SIG} and P_{LO}, respectively, using the electrical spectrum analyser.

STEP 8) The CMRRs for the SIG and the LO are calculated by $P_{\mathrm{DIFF}} - P_{\mathrm{SIG}}$ and $P_{\mathrm{DIFF}} - P_{\mathrm{LO}}$, respectively.

STEP 9) If the target frequency is changed, the procedure is continued from STEP 2).

Annex A
(informative)

Application of optical coherent detection device to RF signal transmission

A.1 Purpose

In a simple application to the RoF system, a photodiode is useful for an optical-to-electrical conversion. A coherent receiver has two identical RF outputs, and thus, some specific applications such as a radar system are applicable for the coherent receiver system.

A.2 Diagrams

An example of a block diagram using a coherent receiver is shown in Figure A.1. This block configuration is adapted for both a communication signal transceiver and a frequency-modulated continuous-wave radar system. Typically, this radar system should have two RF lines: one for the transmitter signal and one for the LO operating the mixer for frequency down-conversion. In this case, an input RoF signal is formed with a frequency-chirped waveform without a carrier component. An optical LO input into the coherent receiver is utilized as a frequency up-conversion LO signal. The frequency separation between the input RoF signal and the optical LO corresponds to the RF frequency at the output. In the system, a phase difference between the in-phase and quadrature-phase outputs has not affect on the quality of output intermediate frequency (IF) signals after the mixer. Typically, the RF coupler or power splitter is utilized for the split of the transmitter signal into two components; however, the insertion loss of the coupler or splitter requires additional power amplifier before and after the coupler or splitter. On the contrary, two independent RF outputs with a rigid phase relationship can be directly connected to the antenna (via an output amplifier) and to the mixer. A simple configuration reduces the footprint and complexity of the radio frontend.

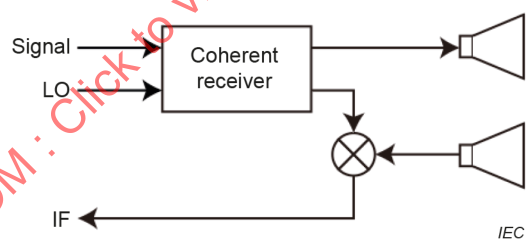


Figure A.1 – Example of block diagram of a radar radio frontend using a coherent receiver